

# High Voltage R&D in Liquid Argon

---

Sarah Lockwitz, *FNAL*

February 14, 2014

# Recent Interest in LAr High Voltage (HV)

---

Experiment	Status
ICARUS	2001, Running 2010
Darkside 50	Running
MicroBooNE	Run this year
CAPTAIN	Built this year
LBNE	?
GLACIER	R&D Phase

# Recent Interest in LAr High Voltage (HV)

---

- Noble liquids are becoming a popular detector medium

Experiment	Status
ICARUS	2001, Running 2010
Darkside 50	Running
MicroBooNE	Run this year
CAPTAIN	Built this year
LBNE	?
GLACIER	R&D Phase

# Recent Interest in LAr High Voltage (HV)

---

- Noble liquids are becoming a popular detector medium
- These often require HV

Experiment	Status	Voltage
ICARUS	2001, Running 2010	75 kV
Darkside 50	Running	60 kV
MicroBooNE	Run this year	128 kV
CAPTAIN	Built this year	50 kV
LBNE	?	170 kV
GLACIER	R&D Phase	1-2 MV

# Recent Interest in LAr High Voltage (HV)

---

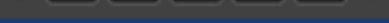
- Noble liquids are becoming a popular detector medium
- These often require HV
- As a result, there's been a lot of interest in this recently

Experiment	Status	Voltage
ICARUS	2001, Running 2010	75 kV
Darkside 50	Running	60 kV
MicroBooNE	Run this year	128 kV
CAPTAIN	Built this year	50 kV
LBNE	?	170 kV
GLACIER	R&D Phase	1-2 MV

# Recent Interest in LAr High Voltage (HV)

- Noble liquids are becoming a popular detector medium
- These often require HV
- As a result, there's been a lot of interest in this recently
  - In November 2013, FNAL hosted the "High Voltage in Nobel Liquids" workshop with ~40 attendees

Experiment	Status	Voltage
ICARUS	2001, Running 2010	75 kV
Darkside 50	Running	60 kV
MicroBooNE	Run this year	128 kV
CAPTAIN	Built this year	50 kV
LBNE	?	170 kV
GLACIER	R&D Phase	1-2 MV



# High Voltage in Noble Liquids

8-9 November 2013 *Fermi National Accelerator Laboratory*  
US/Central timezone

**Overview**  
Agenda  
Participants List

This workshop will provide a forum to discuss current activities and the behavior of high voltage in noble liquids. The workshop will focus on the neutrino, dark matter, and electric dipole moment searches, the design of making feed throughs, understanding dielectric properties of high voltage systems. These issues are relevant for a broad range of applications.

# High Voltage Workshop Highlights

---

# High Voltage Workshop Highlights

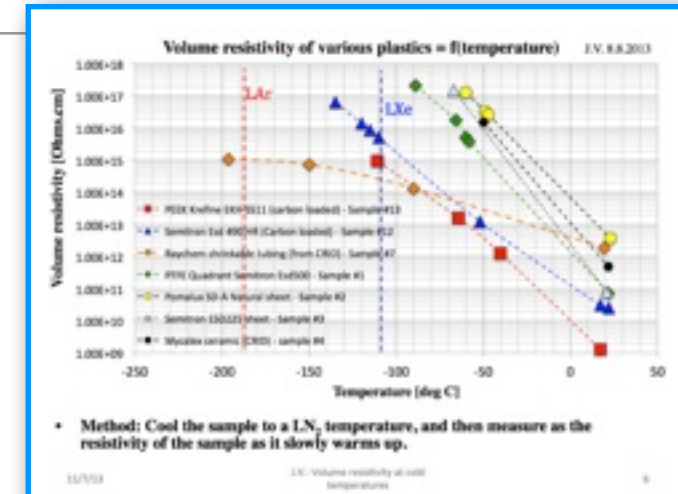
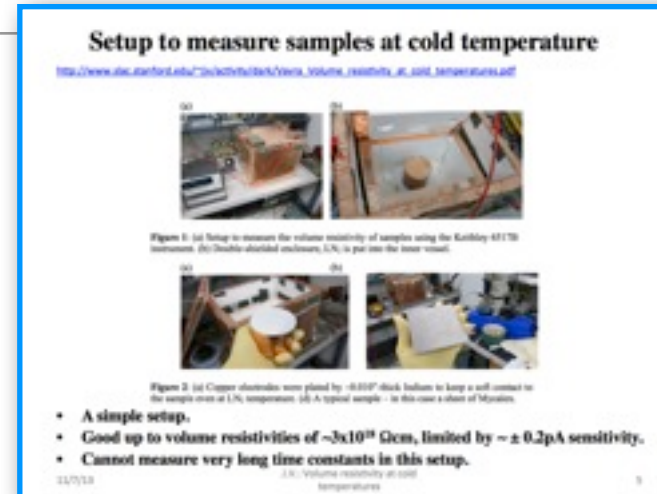
---

- Some highlights from the workshop included:



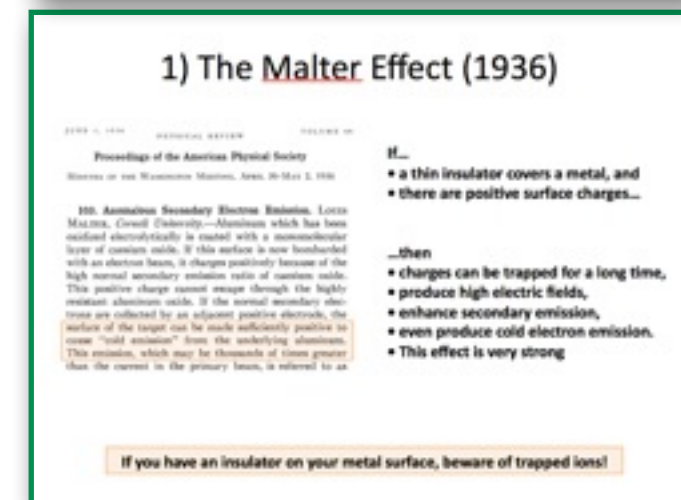
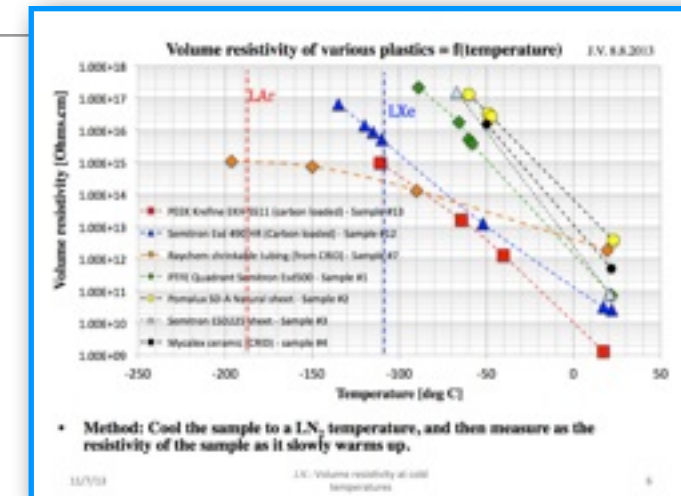
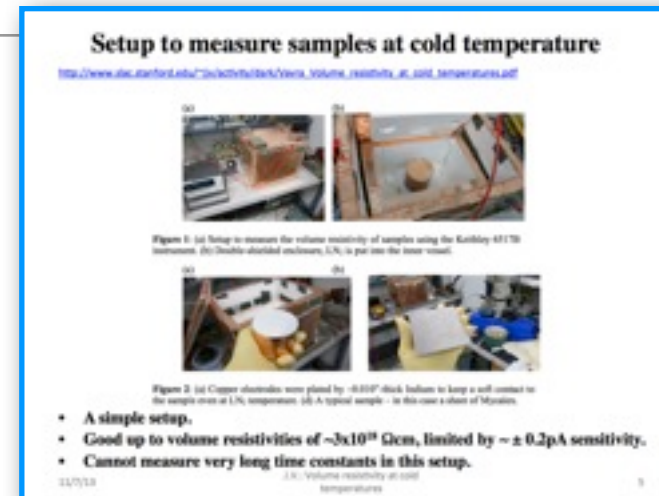
# High Voltage Workshop Highlights

- Some highlights from the workshop included:
  - **Va'vra** (SLAC): measured resistivities at LXe temperatures; advocates using slightly conductive materials



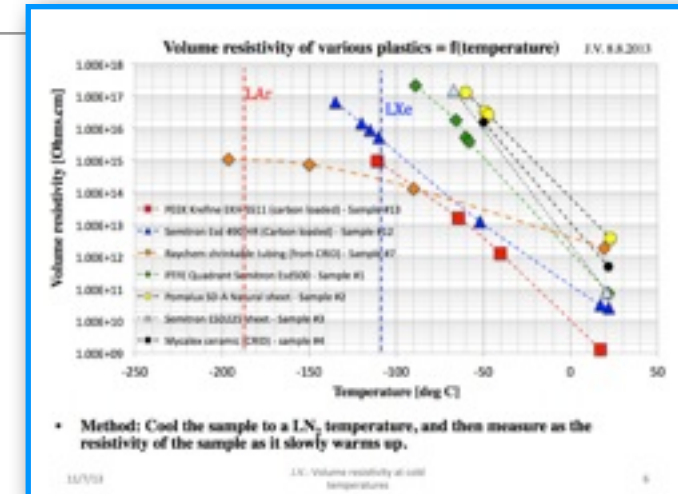
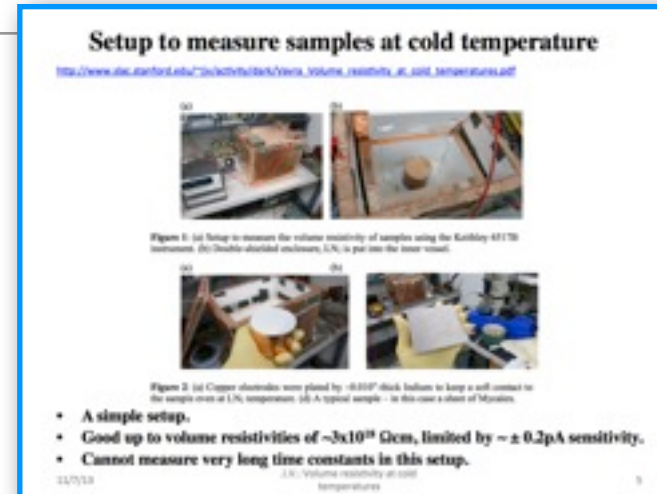
# High Voltage Workshop Highlights

- Some highlights from the workshop included:
  - **Va'vra** (SLAC): measured resistivities at LXe temperatures; advocates using slightly conductive materials
  - **Pereverzev** (LLNL): Discussed monolayer ideas and tests



# High Voltage Workshop Highlights

- Some highlights from the workshop included:
  - **Va'vra** (SLAC): measured resistivities at LXe temperatures; advocates using slightly conductive materials
  - **Pereverzev** (LLNL): Discussed monolayer ideas and tests
  - **Resnati** (ETH Zurich): R&D for Glacier (HV @ MV scale); (1 cm LAr dielectric strength test [here](#))
  - and [more](#)...



1) The **Malter** Effect (1936)

PROF. J. L. MALTER  
 PROCEEDINGS OF THE AMERICAN PHYSICAL SOCIETY  
 MEETING AT THE WASHINGTON MOUNTAIN, ARIZ., 30-MAY 2, 1936

Hdr. Anomalous Secondary Electron Emission, LOUIS MALTER, Cornell University.—Aluminum which has been oxidized electrolytically is coated with a monomolecular layer of cationic oxide. If this surface is now bombarded with an electron beam, it charges positively because of the high internal secondary emission ratio of cationic oxide. This positive charge cannot escape through the highly resistant aluminum oxide. If the several secondary electrons are collected by an adjacent positive electrode, the surface of the target can be made sufficiently positive to cause "cold emission" from the underlying aluminum. This emission, which may be thousands of times greater than the current in the primary beam, is referred to as

If...  
 • a thin insulator covers a metal, and  
 • there are positive surface charges...

...then  
 • charges can be trapped for a long time,  
 • produce high electric fields,  
 • enhance secondary emission,  
 • even produce cold electron emission.  
 • This effect is very strong

If you have an insulator on your metal surface, beware of trapped ions!

- Electrical breakdown in LAr
- Not many recent papers in the literature:
    - Swan, Lewis and Gallagher in the 1960s
  - Non trivial mechanism:
    - Townsend avalanche
    - Impurities effects
    - Electron emission from metals
    - Field emission from the cathode
    - Space charge effect
    - Suspended solid particles effect
    - Nucleation, cavitation and bubble effect
- Filippo Resnati - High Voltage in Noble Liquids - FNAL - November 9th, 2013 18

- R&D on HV
- Unknowns to be known before the final design:
    - Liquid argon dielectric rigidity versus electrode distance
    - Bubble and liquid argon purity effects on discharges
    - Argon ionization and space charge effects
    - Electrode material impact and properties of insulating materials
- Filippo Resnati - High Voltage in Noble Liquids - FNAL - November 9th, 2013 24

# High Voltage Workshop Highlights

---

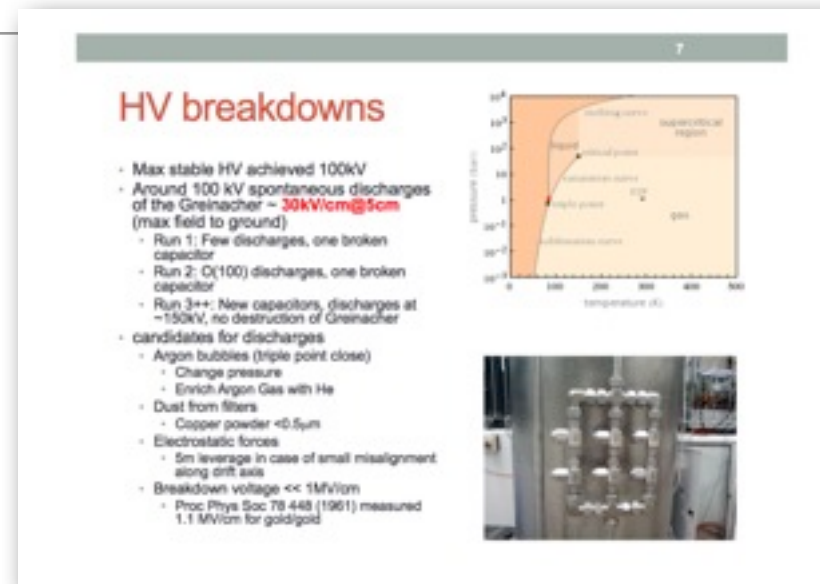
# High Voltage Workshop Highlights

---

- Also, uB colleagues at BERN have been involved on LAr HV R&D:

# High Voltage Workshop Highlights

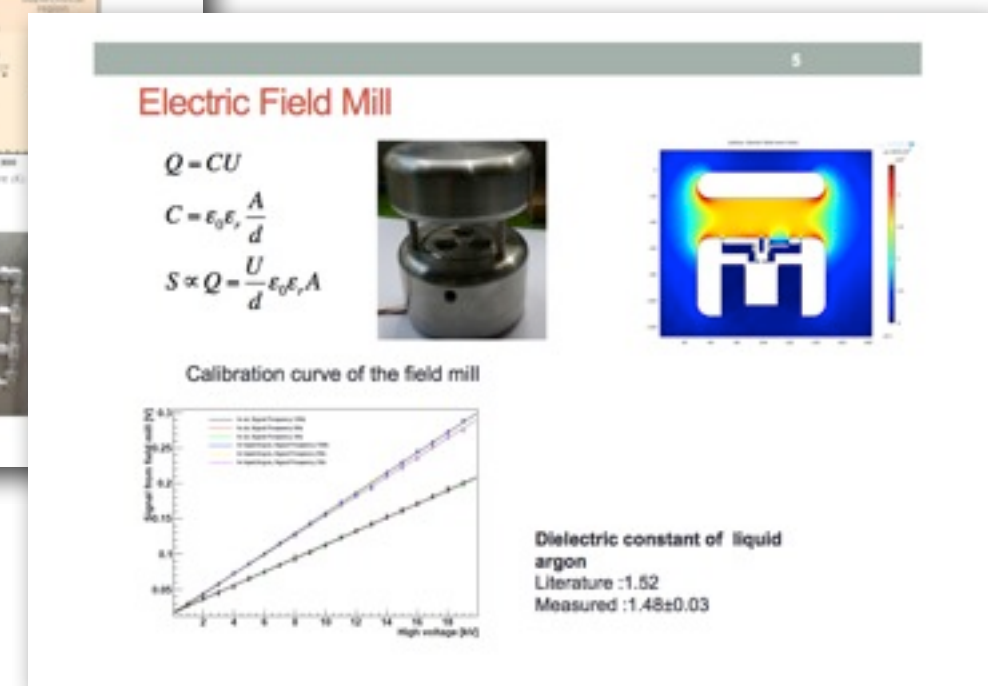
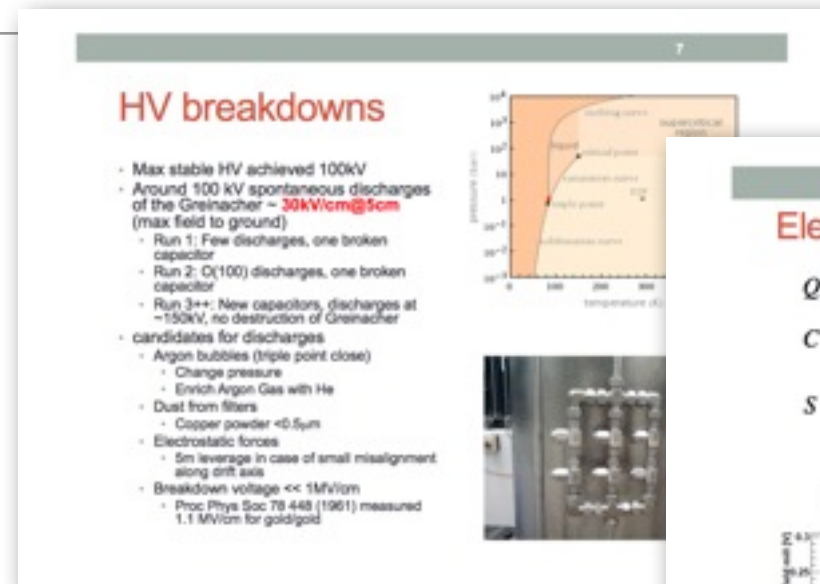
- Also, uB colleagues at BERN have been involved on LAr HV R&D:
  - ARGONTUBE: 5 m drift, uses Greinacher/Cockcroft-Walton for HV (max stable 100 kV)





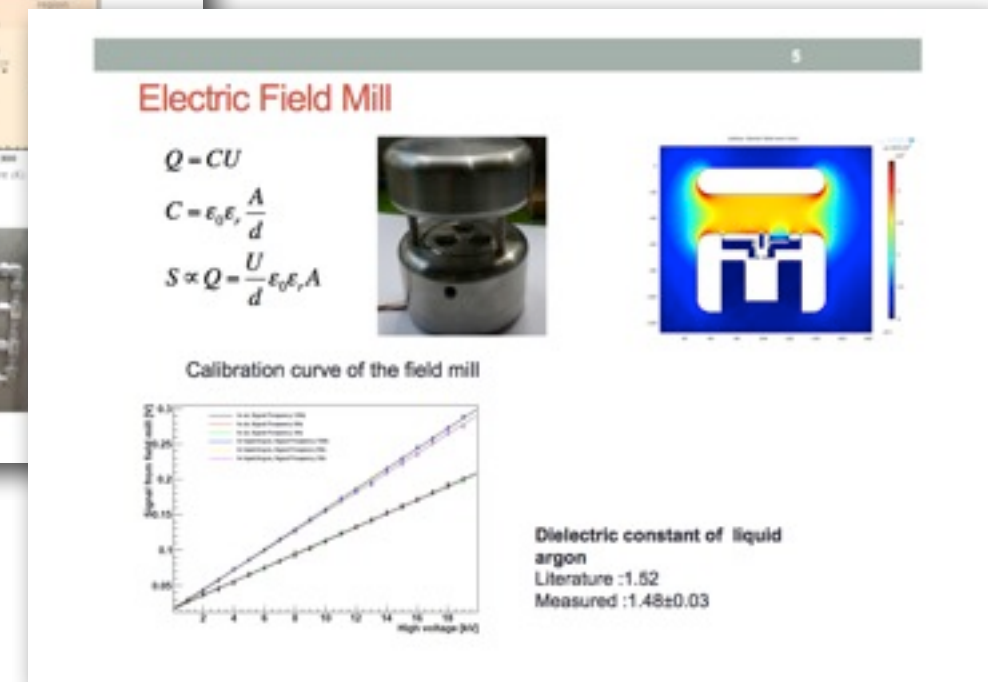
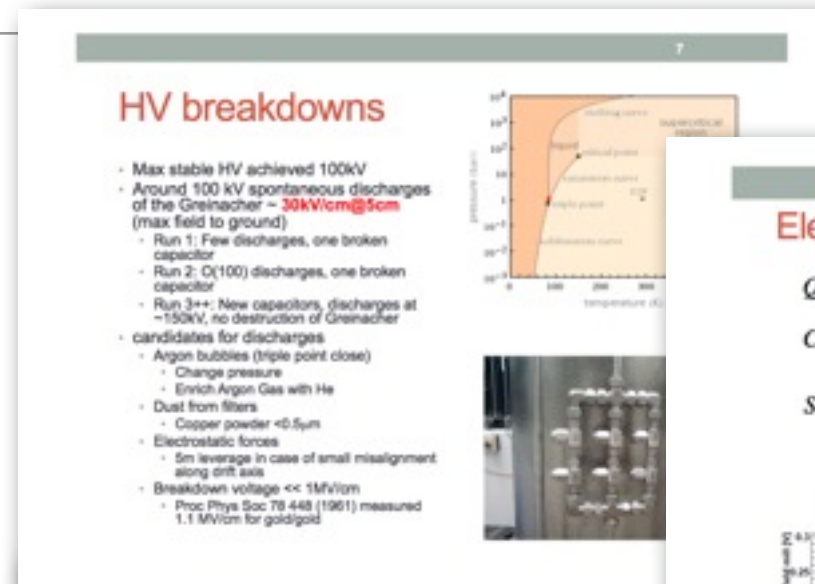
# High Voltage Workshop Highlights

- Also, uB colleagues at BERN have been involved on LAr HV R&D:
  - ARGONTUBE: 5 m drift, uses Greinacher/Cockcroft-Walton for HV (max stable 100 kV)
  - Measured the dielectric



# High Voltage Workshop Highlights

- Also, uB colleagues at BERN have been involved on LAr HV R&D:
  - ARGONTUBE: 5 m drift, uses Greinacher/Cockcroft-Walton for HV (max stable 100 kV)
  - Measured the dielectric
  - Measuring electric strength of LAr vs. distance and purity (issue) ([link](#))



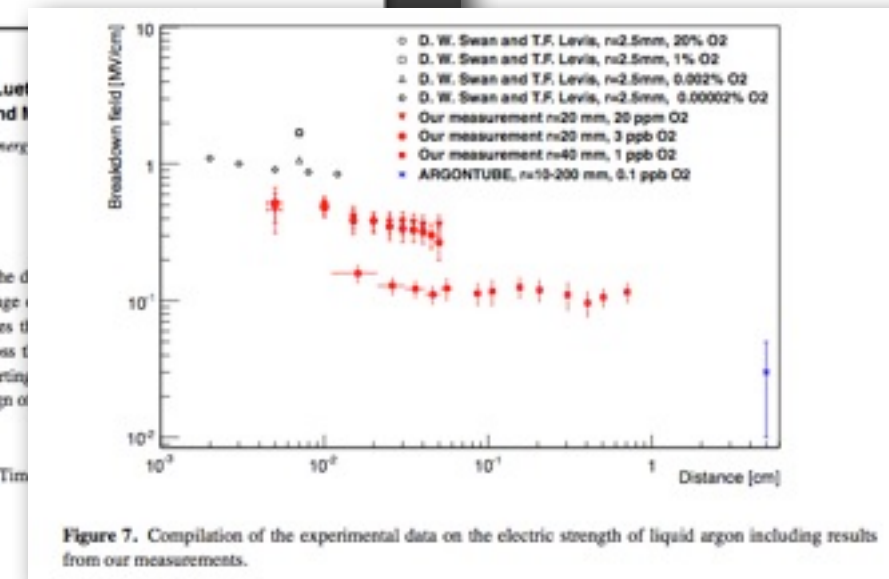
arXiv:1401.6693v1 [physics.ins-det] 26 Jan 2014

## Experimental study of electric breakdowns in liquid argon at centimeter scale

A. Blatter, A. Ereditato, C.-C. Hsu, S. Janos, I. Kreslo, M. Luetz, C. Rudolf von Rohr, M. Schenk, T. Strauss, M. S. Weber and I. Zappalà  
Albert Einstein Center for fundamental Physics, Laboratory for High Energy Physics, University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland  
E-mail: [igor.kreslo@hep.unibe.ch](mailto:igor.kreslo@hep.unibe.ch)

**ABSTRACT:** In this paper we present results on measurements of the electric strength of liquid argon near its boiling point and cathode-anode distances in the range of 1 to 10 cm. We show that at such distances the electric strength is as low as 40 kV/cm. Flash-overs across the gap are observed for a length of 300 mm starting from the cathode. These results contribute to set reference for the breakdown-free design of Liquid Argon Time Projection Chambers (LAr TPC).

**KEYWORDS:** Dielectric strength, electric breakdown, liquid argon, Time Projection Chamber





# Our Experience: LAr Electric Strength

---

# Our Experience: LAr Electric Strength

---

- I work with Dr. Jostlein on the HV for MicroBooNE



# Our Experience: LAr Electric Strength

---

- I work with Dr. Jostlein on the HV for MicroBooNE
- For me, the beginning of this work involved testing a prototype feedthrough in an open LAr dewar





# Our Experience: LAr Electric Strength

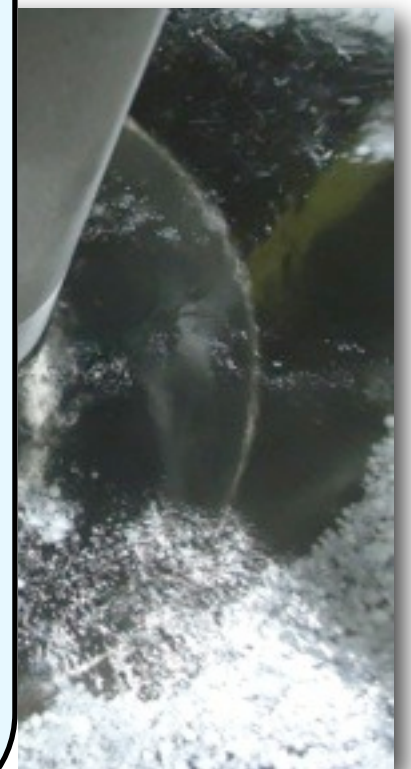
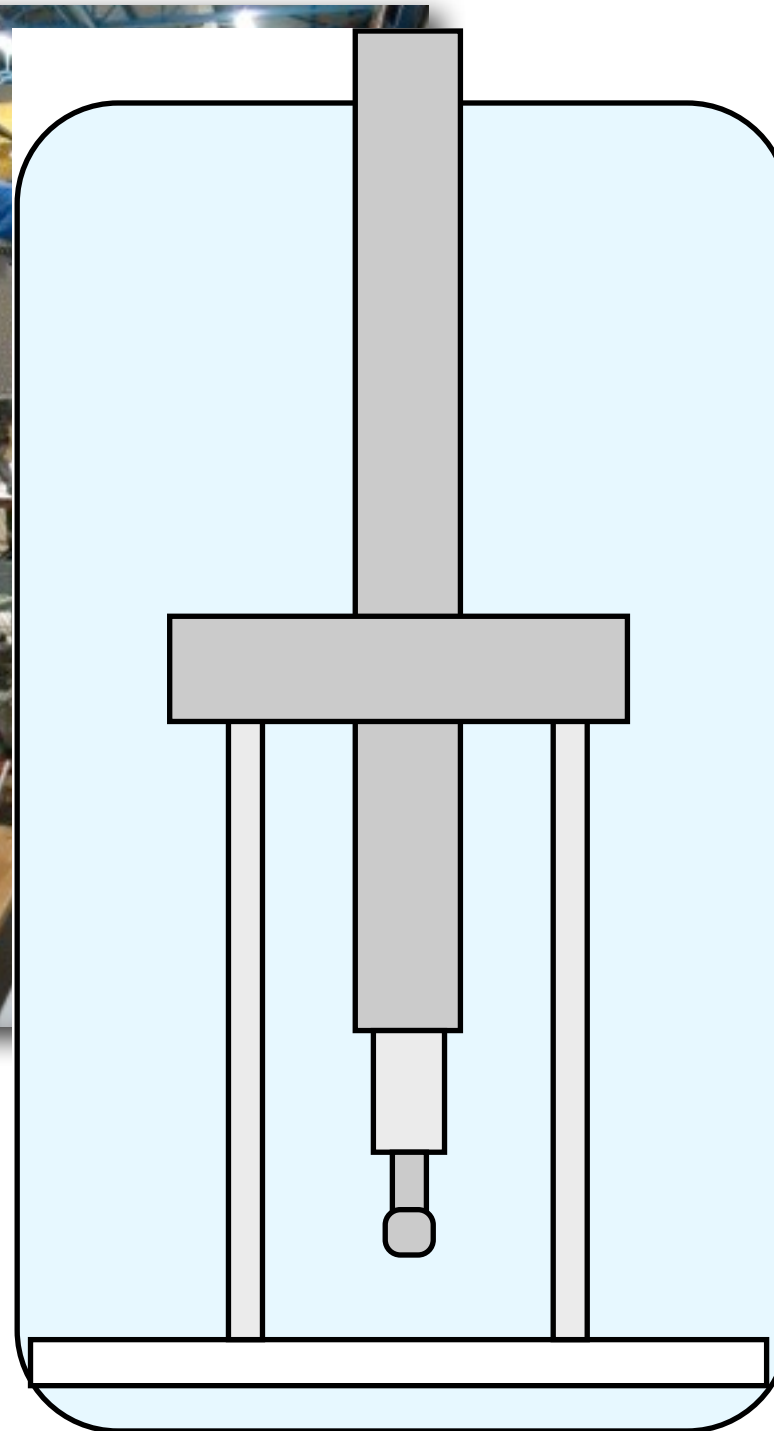
---

- I work with Dr. Jostlein on the HV for MicroBooNE
- For me, the beginning of this work involved testing a prototype feedthrough in an open LAr dewar
- Trips/sparks were not an infrequent phenomenon for us
  - However, we generally thought they were *along* the FT



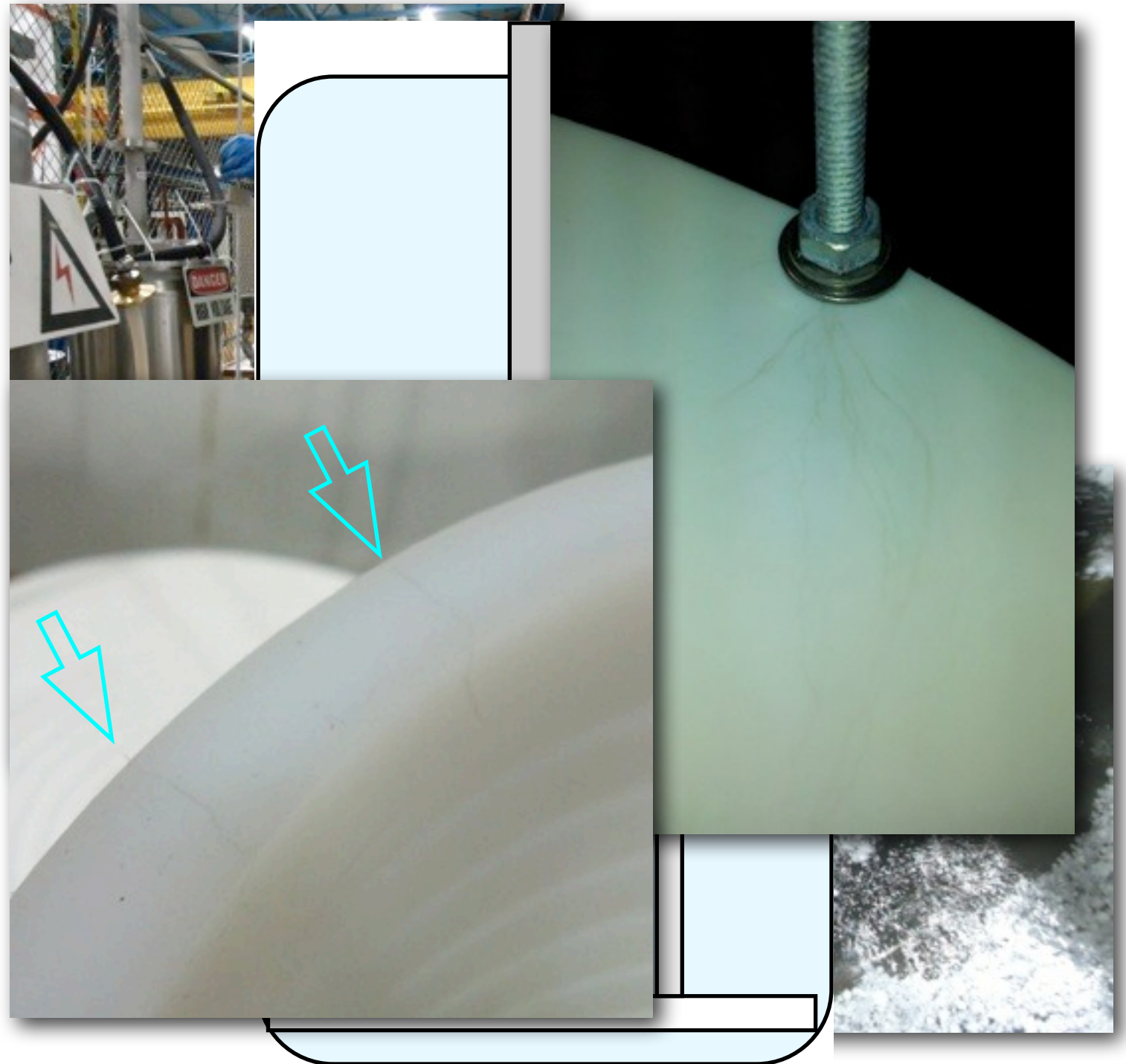
# Our Experience: LAr Electric Strength

- I work with Dr. Jostlein on the HV for MicroBooNE
- For me, the beginning of this work involved testing a prototype feedthrough in an open LAr dewar
- Trips/sparks were not an infrequent phenomenon for us
  - However, we generally thought they were *along* the FT
  - Until we saw them *through* the argon!



# Our Experience: LAr Electric Strength

- I work with Dr. Jostlein on the HV for MicroBooNE
- For me, the beginning of this work involved testing a prototype feedthrough in an open LAr dewar
- Trips/sparks were not an infrequent phenomenon for us
  - However, we generally thought they were *along* the FT
  - Until we saw them *through* the argon!



# Our Experience: LAr Electric Strength

---



# Our Experience: LAr Electric Strength

- This caught our eye because people were quoting  $\sim 1.4$  MV/cm for the electric strength of LAr

TABLE 6.2  
*Electric strengths of liquefied gases*

Liquid	Strength (MV cm <sup>-1</sup> )
Nitrogen	1.6–1.88
Oxygen	2.38
Argon	1.10–1.42
Hydrogen	> 1.0
Helium I, II	0.7



# Our Experience: LAr Electric Strength

- This caught our eye because people were quoting  $\sim 1.4$  MV/cm for the electric strength of LAr
- Upon closer inspection, this value seems to come from a measurement at very small distances using very small spheres

TABLE 6.2  
*Electric strengths of liquefied gases*

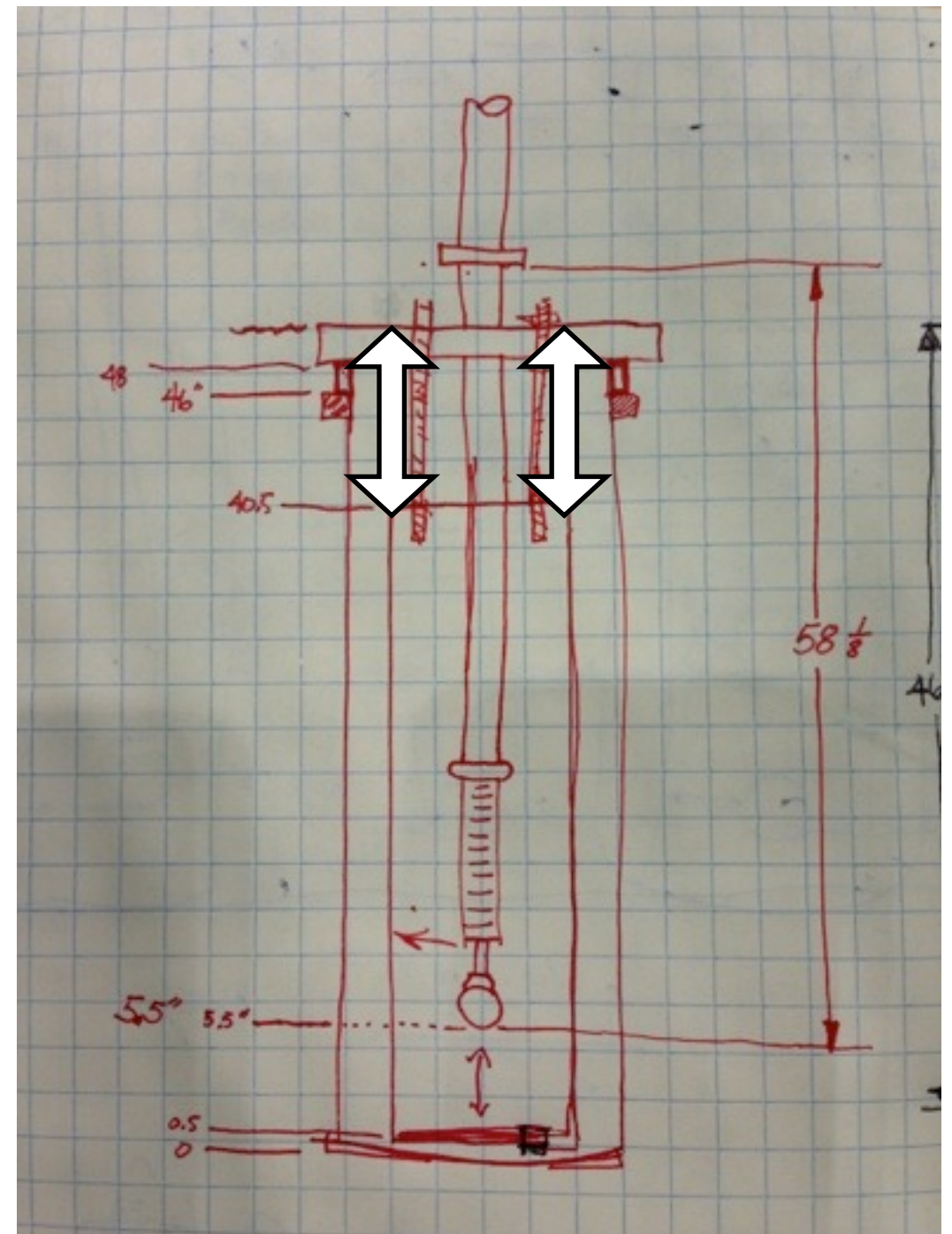
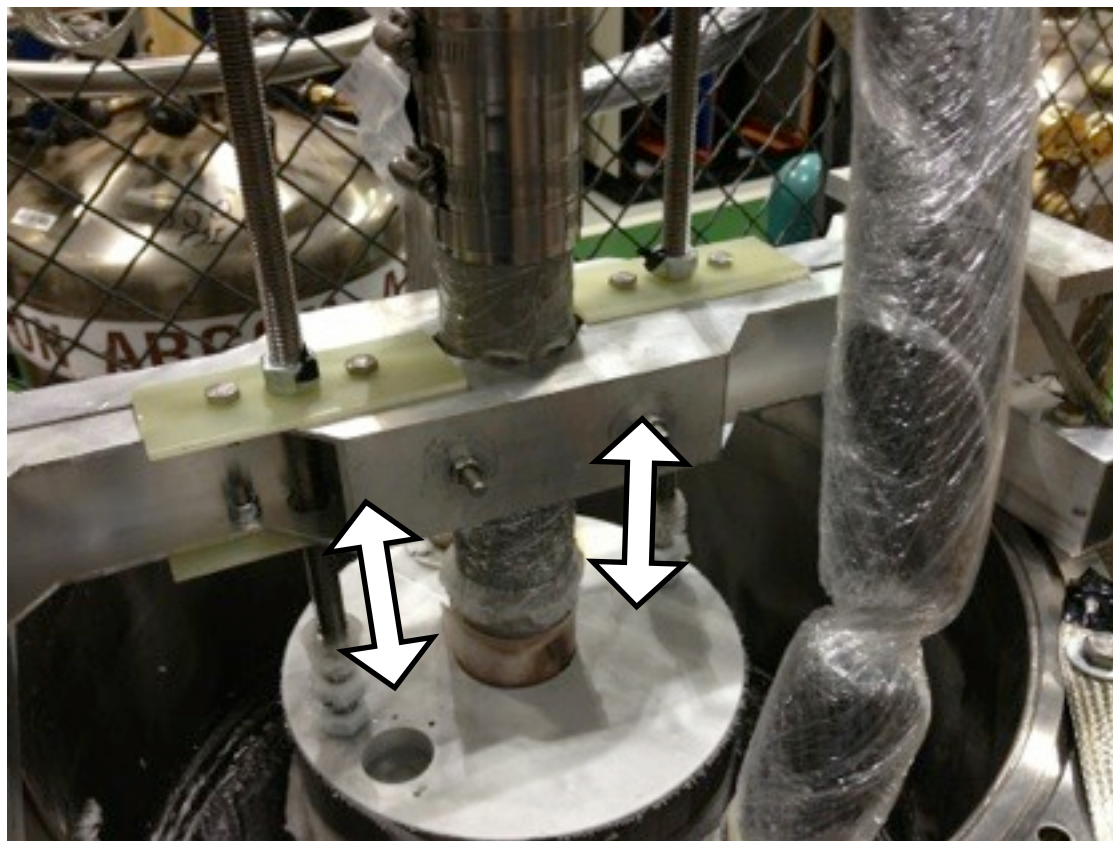
Liquid	Strength (MV cm <sup>-1</sup> )
Nitrogen	1.6–1.88
Oxygen	2.38
Argon	1.10–1.42
Hydrogen	> 1.0
Helium I, II	0.7

The apparatus and experimental techniques were the same as those described in the earlier paper (Swan and Lewis 1960). The electrodes were 5 mm diameter spheres and the electrode spacing could be adjusted externally by means of a micrometer. The procedure for obtaining reproducible surface oxide conditions

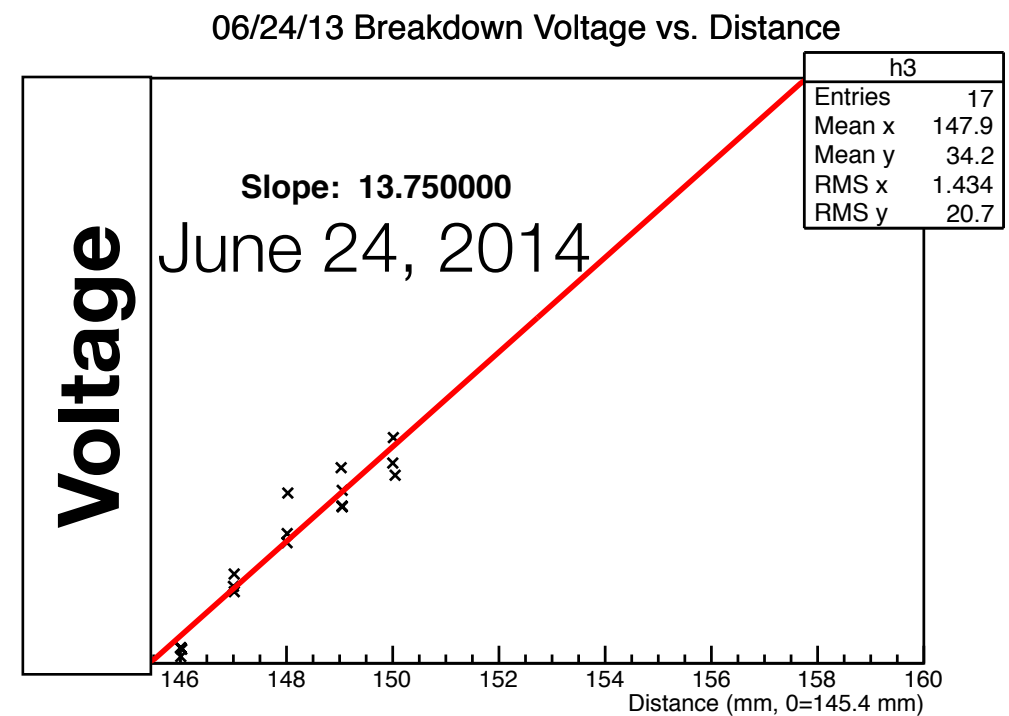
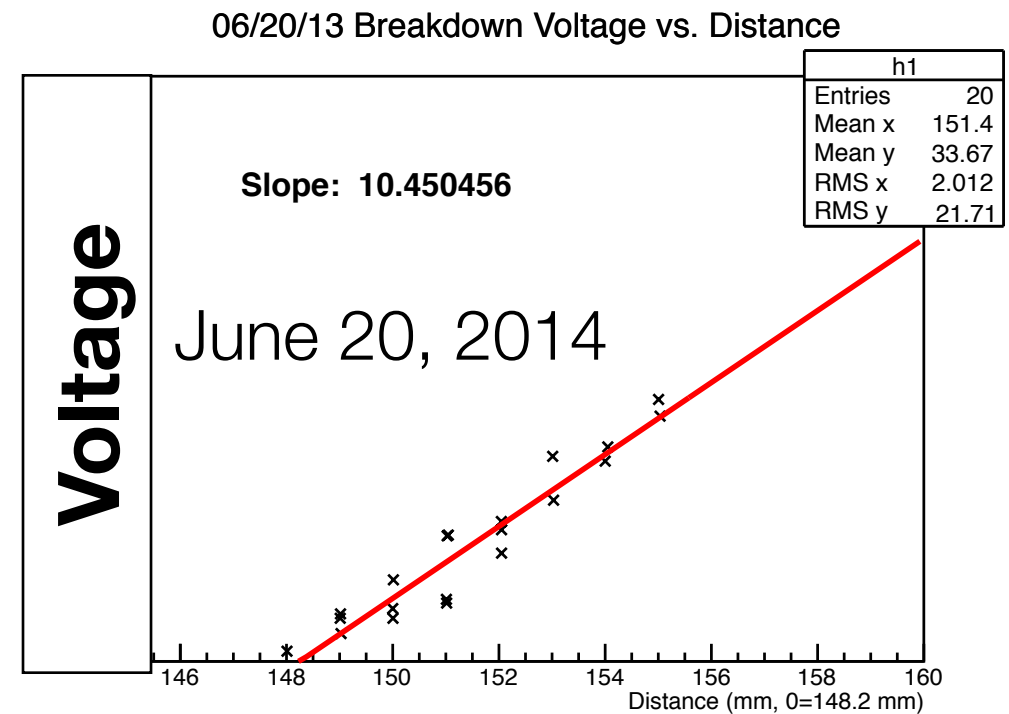
less than 1  $\mu$ sec for electrode spacings of about  $5 \times 10^{-3}$  cm. In the present case for liquid argon at similar spacings  $T_0$  is seen to be greater than 10  $\mu$ sec for most of the electrode

# Our Experience: LAr Electric Strength

- This led us to try to measure the electric strength of LAr vs. distance at DAB this past summer
  - *caveat*: This is in an open dewar (impurities)



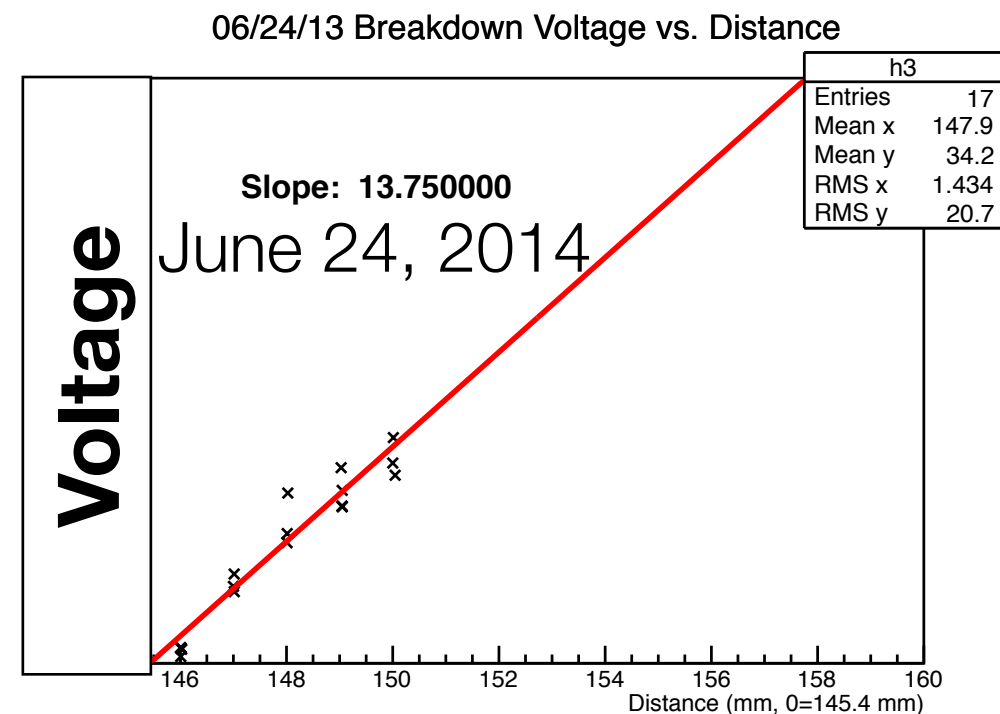
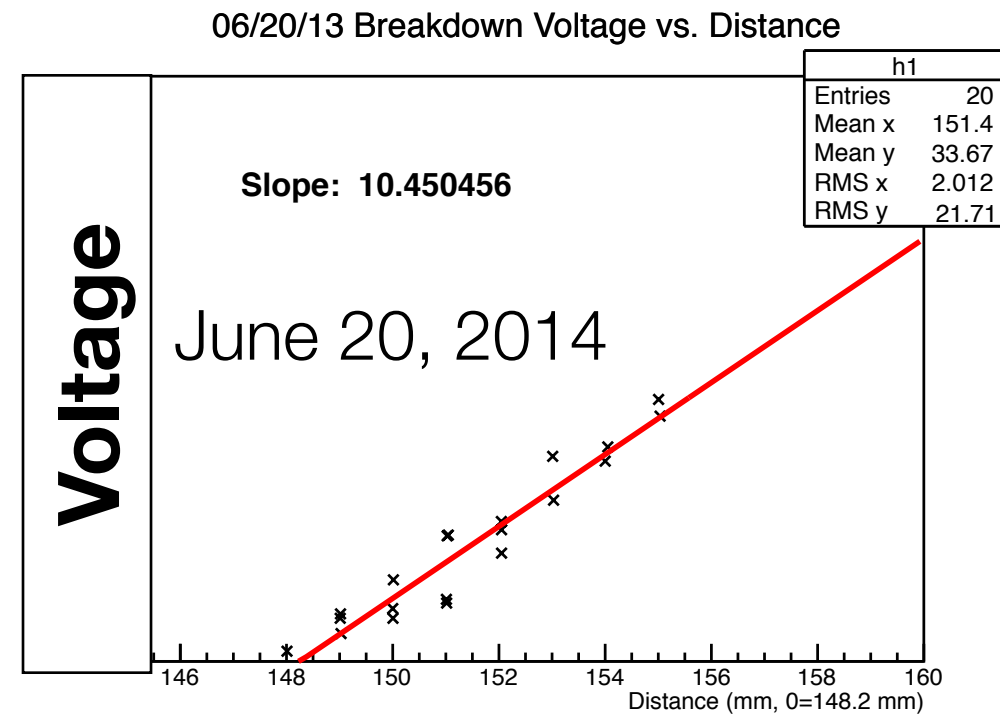
# Our Experience: LAr Electric Strength





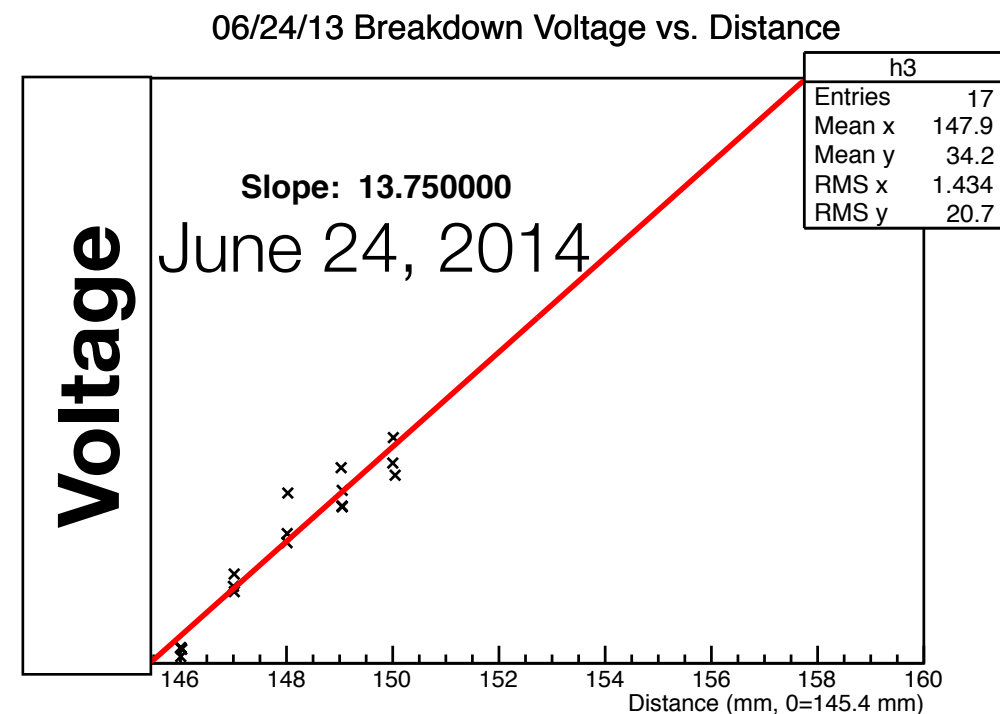
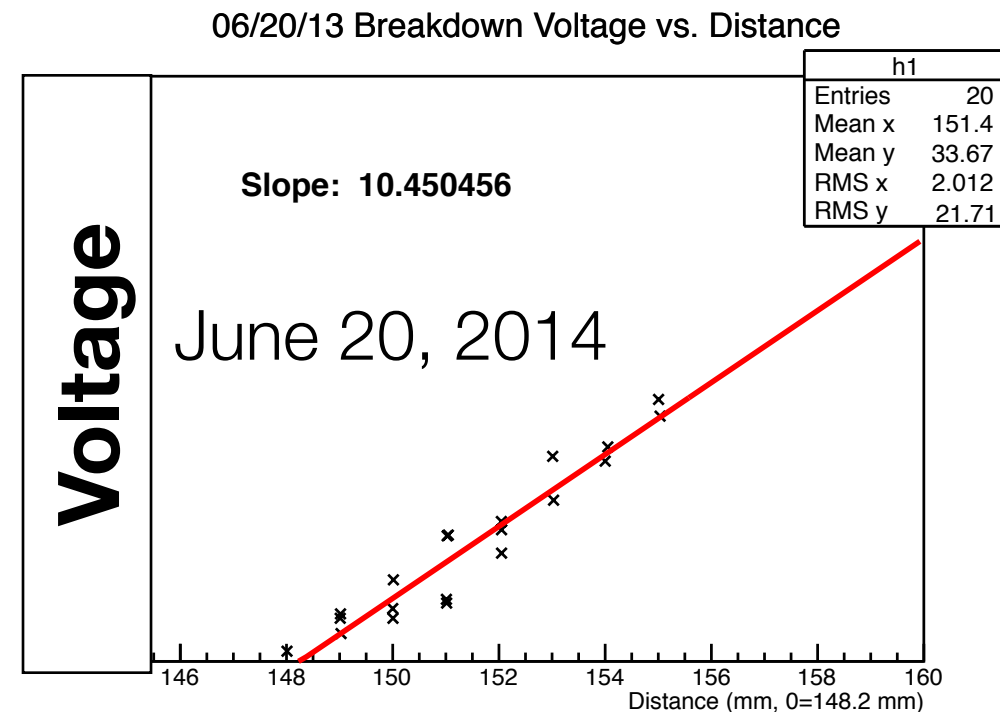
# Our Experience: LAr Electric Strength

- The breakdown voltage is indeed varying with distance



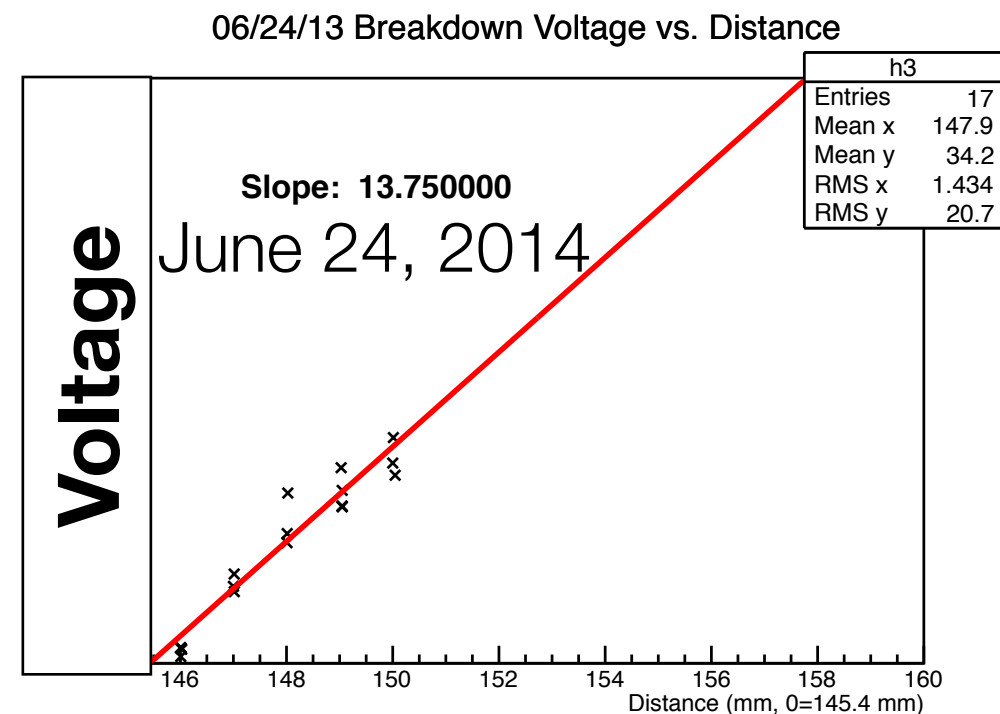
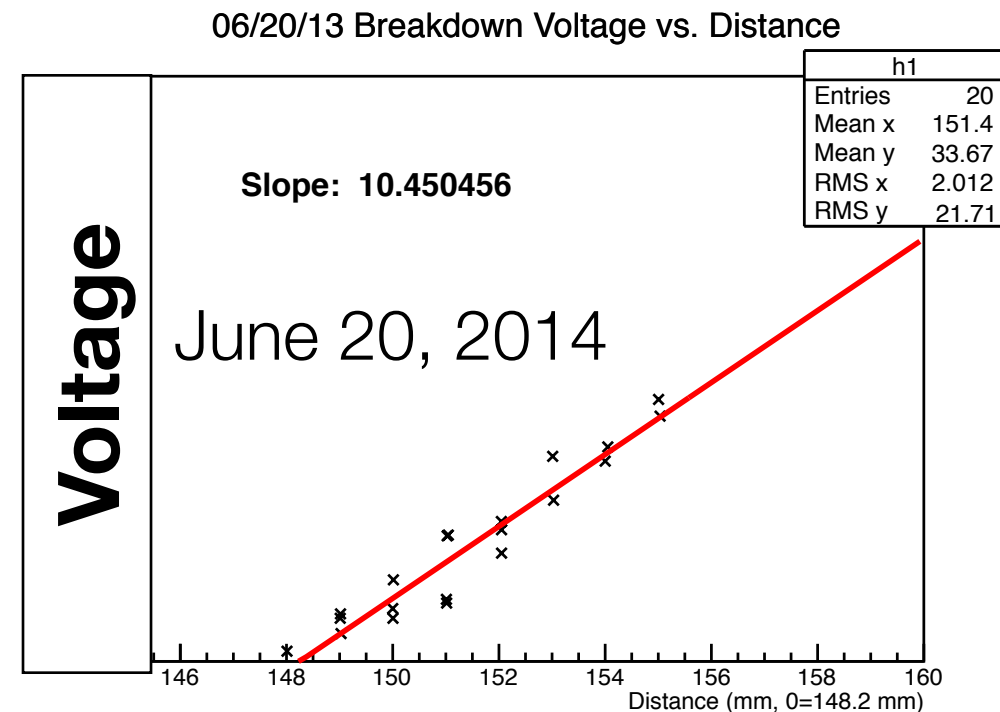
# Our Experience: LAr Electric Strength

- The breakdown voltage is indeed varying with distance
  - → **The breakdown is occurring through the LAr**



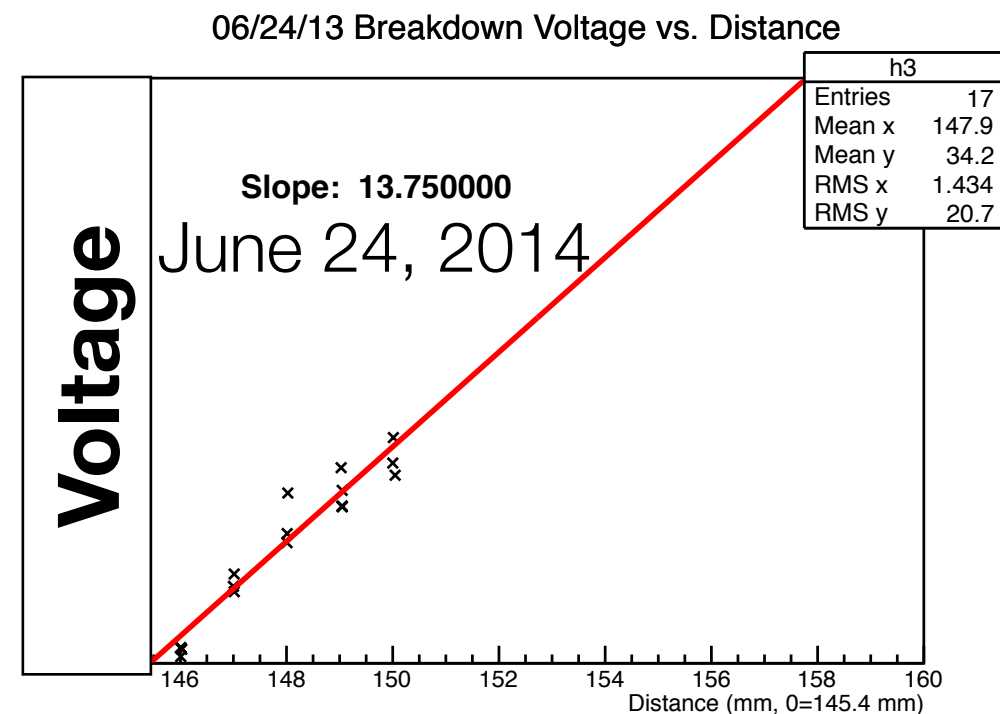
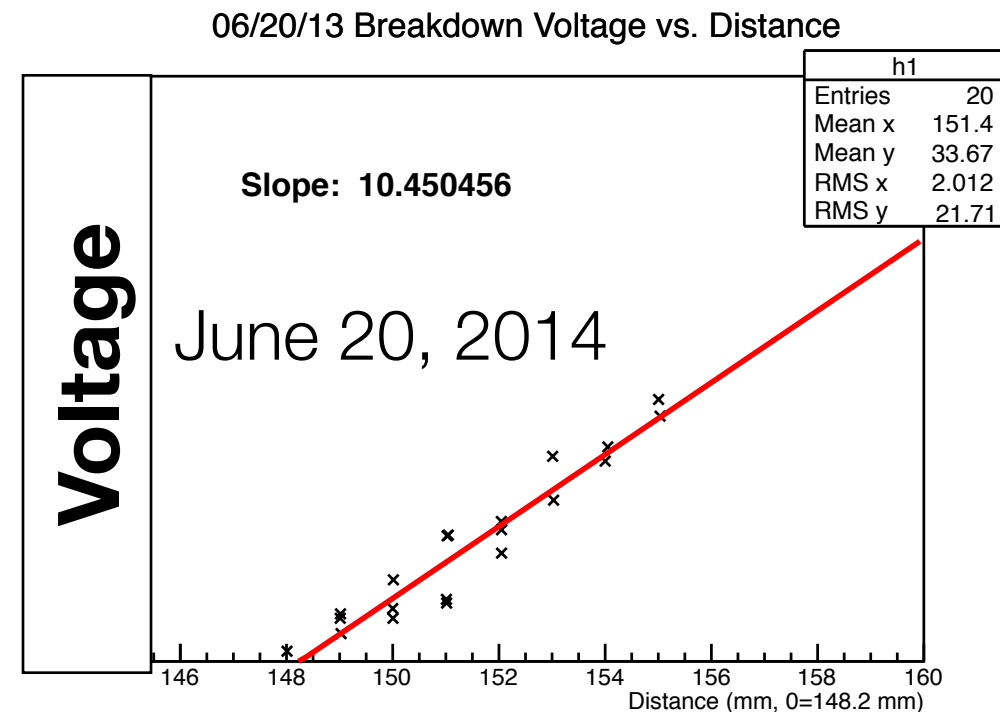
# Our Experience: LAr Electric Strength

- The breakdown voltage is indeed varying with distance
  - → **The breakdown is occurring through the LAr**
- The different dates were meant to explore contamination effects



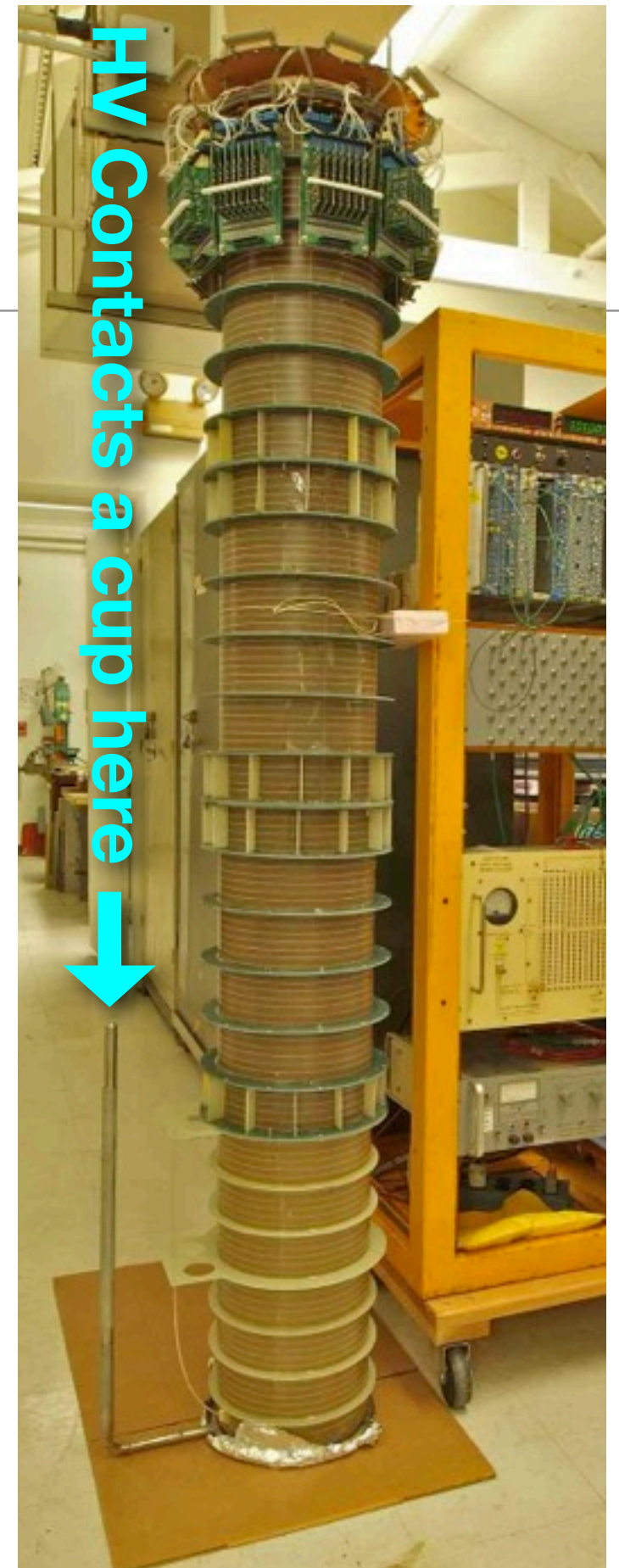
# Our Experience: LAr Electric Strength

- The breakdown voltage is indeed varying with distance
  - → **The breakdown is occurring through the LAr**
- The different dates were meant to explore contamination effects
  - The longer the argon was exposed to air, the more oxygen would diffuse in it



# Our Experience: Long Bo HV

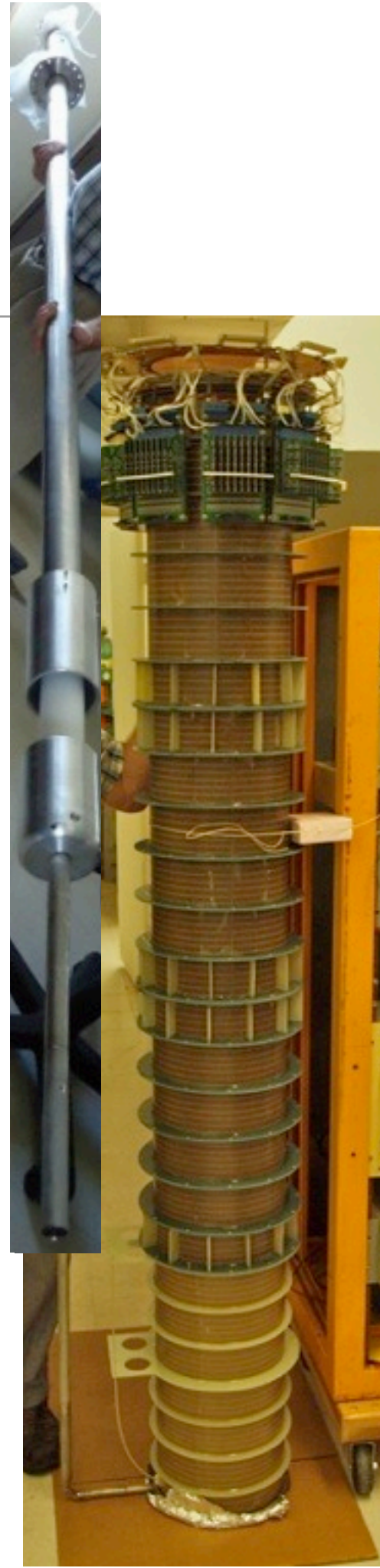
- We also supplied the HV for Long Bo
- Long Bo was a 2 m long drift TPC put in LAPD last year
  - 2 m drift with 500 V/cm --> 100 kV
  - FT was tested to 120 kV for a few hours (open dewar & power supply could not be left)





# Our Experience: Long Bo HV

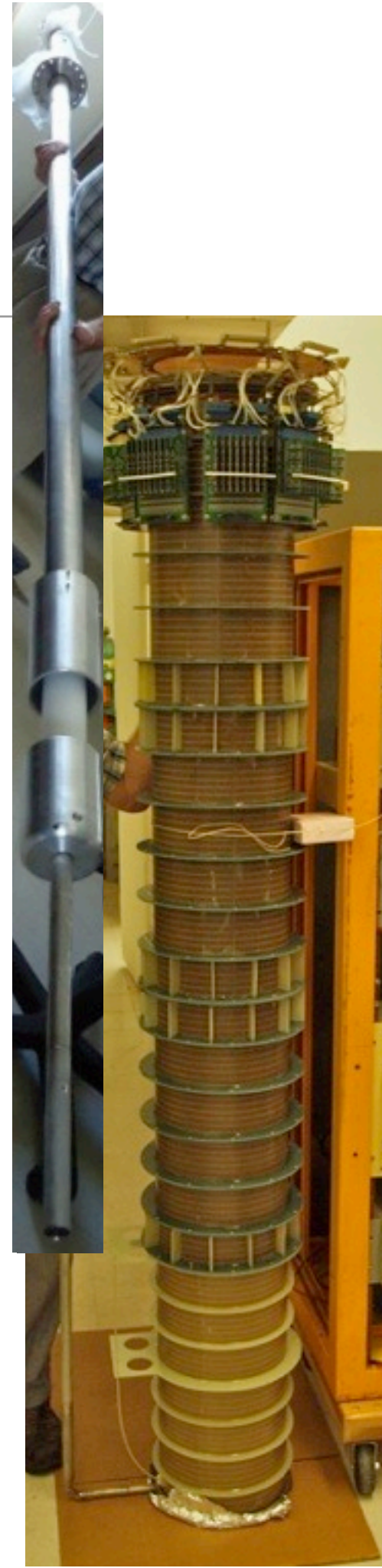
---



Not to scale or proper location by any stretch of the imagination

# Our Experience: Long Bo HV

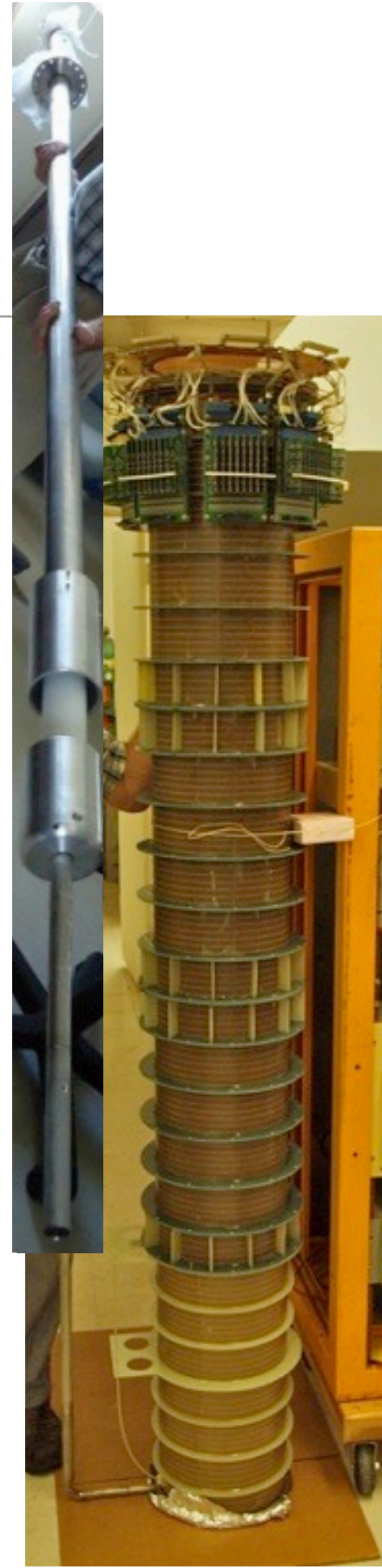
- We had a problem with Long Bo HV



Not to scale or proper location by any stretch of the imagination

# Our Experience: Long Bo HV

- We had a problem with Long Bo HV
  - There was an incident the first time it was turned on (not the fault of the HV)

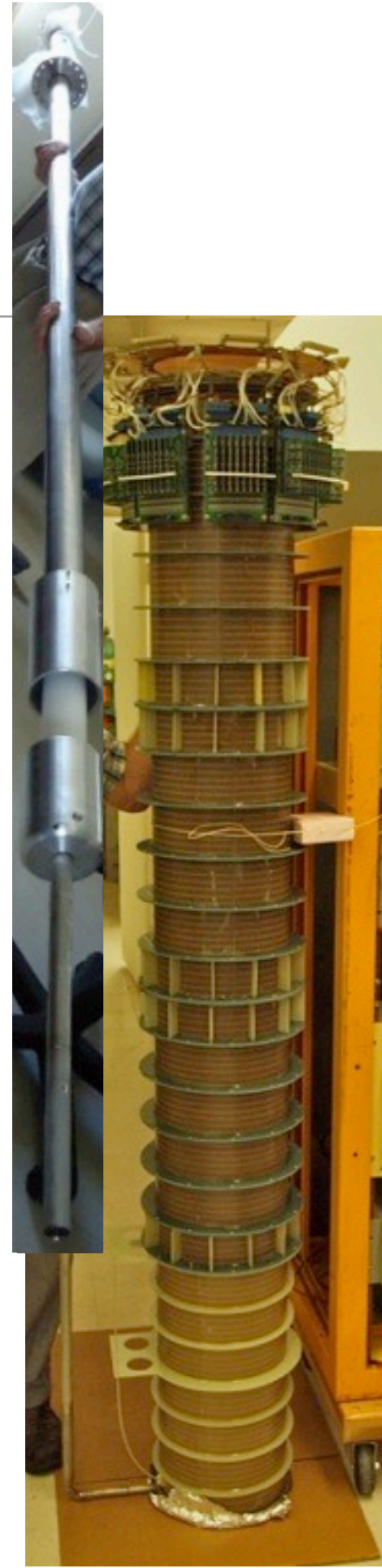


Not to scale or proper location by any stretch of the imagination



# Our Experience: Long Bo HV

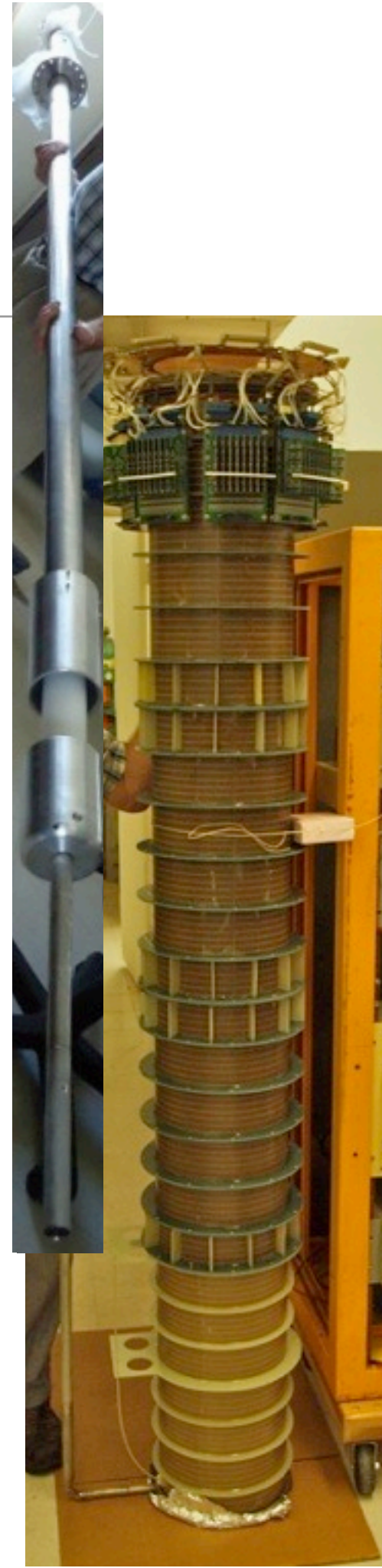
- We had a problem with Long Bo HV
  - There was an incident the first time it was turned on (not the fault of the HV)
  - The HV never held 100 kV for more than a few seconds after that



Not to scale or proper location by any stretch of the imagination

# Our Experience: Long Bo HV

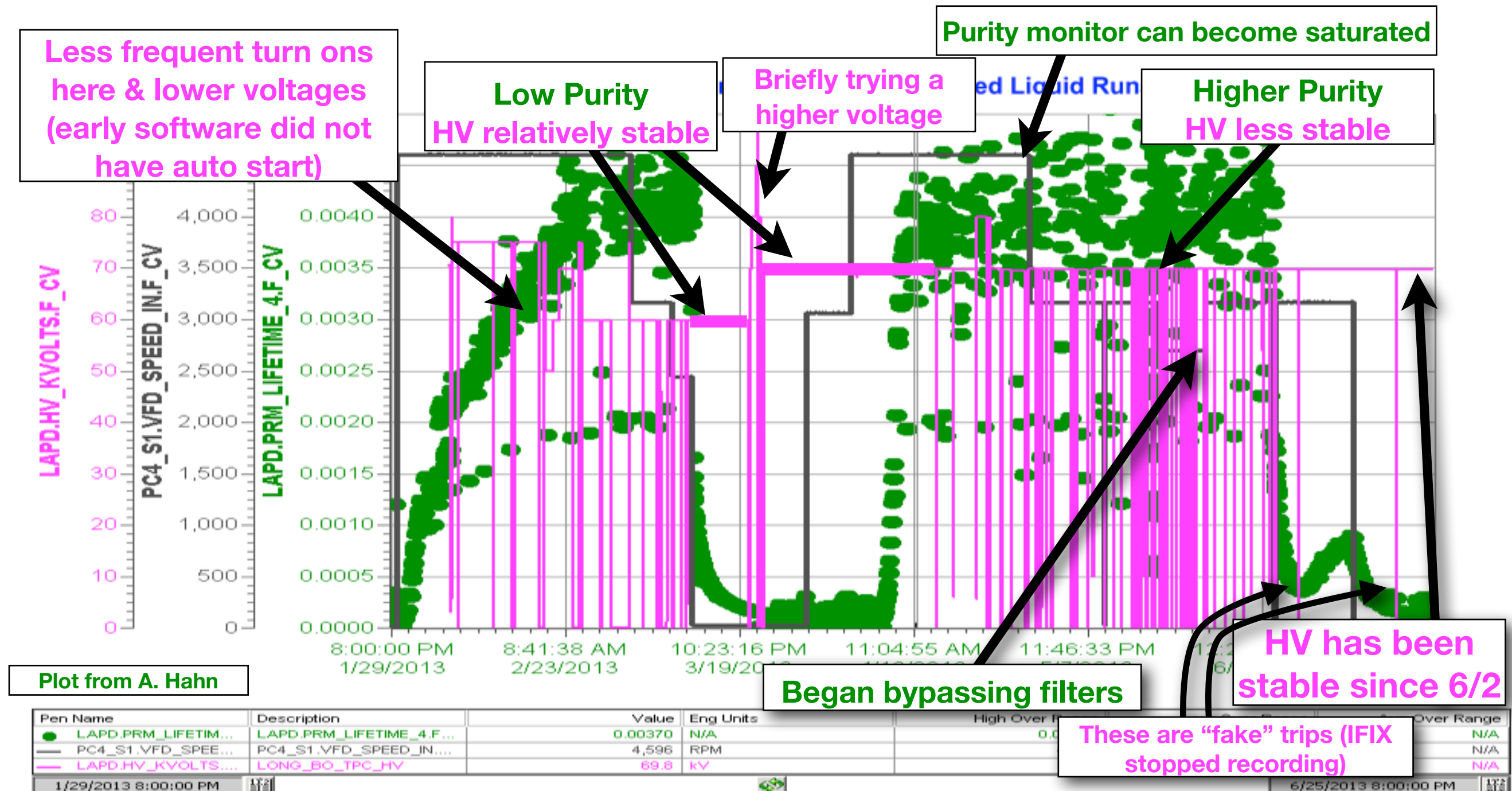
- We had a problem with Long Bo HV
  - There was an incident the first time it was turned on (not the fault of the HV)
  - The HV never held 100 kV for more than a few seconds after that
  - We operated at lower voltages but still saw a trip every day or so



Not to scale or proper location by any stretch of the imagination

# Our Experience: Long Bo HV

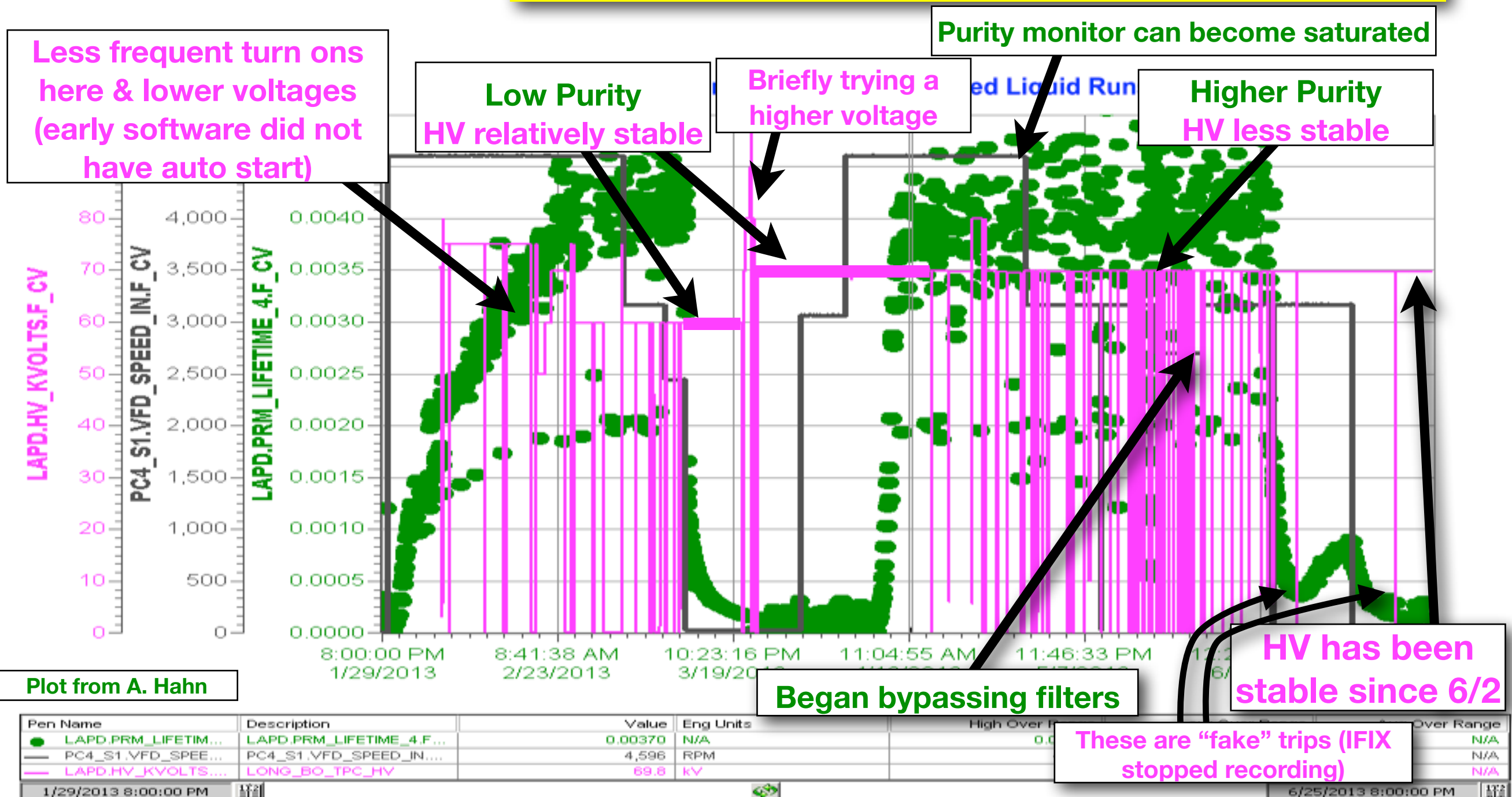
- After a pump failure, we noted HV stability
- We eventually determined the HV stability is related to the purity of the LAr





# Our Experience: Long Bo HV

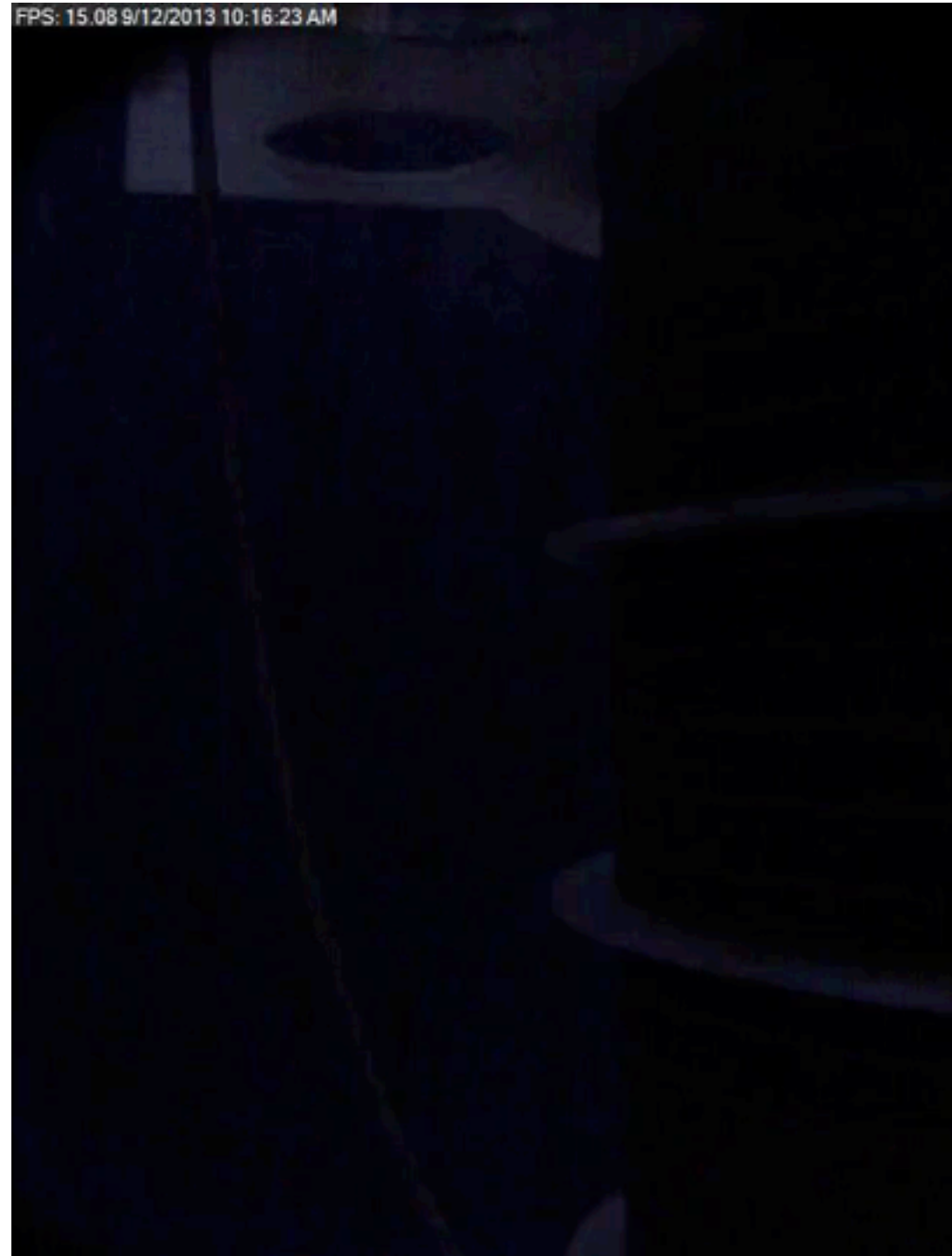
- After a pump failure, we noted HV stability
- We eventually determined **the HV stability is related to the purity of the LAr**



# Our Experience: Long Bo HV

---

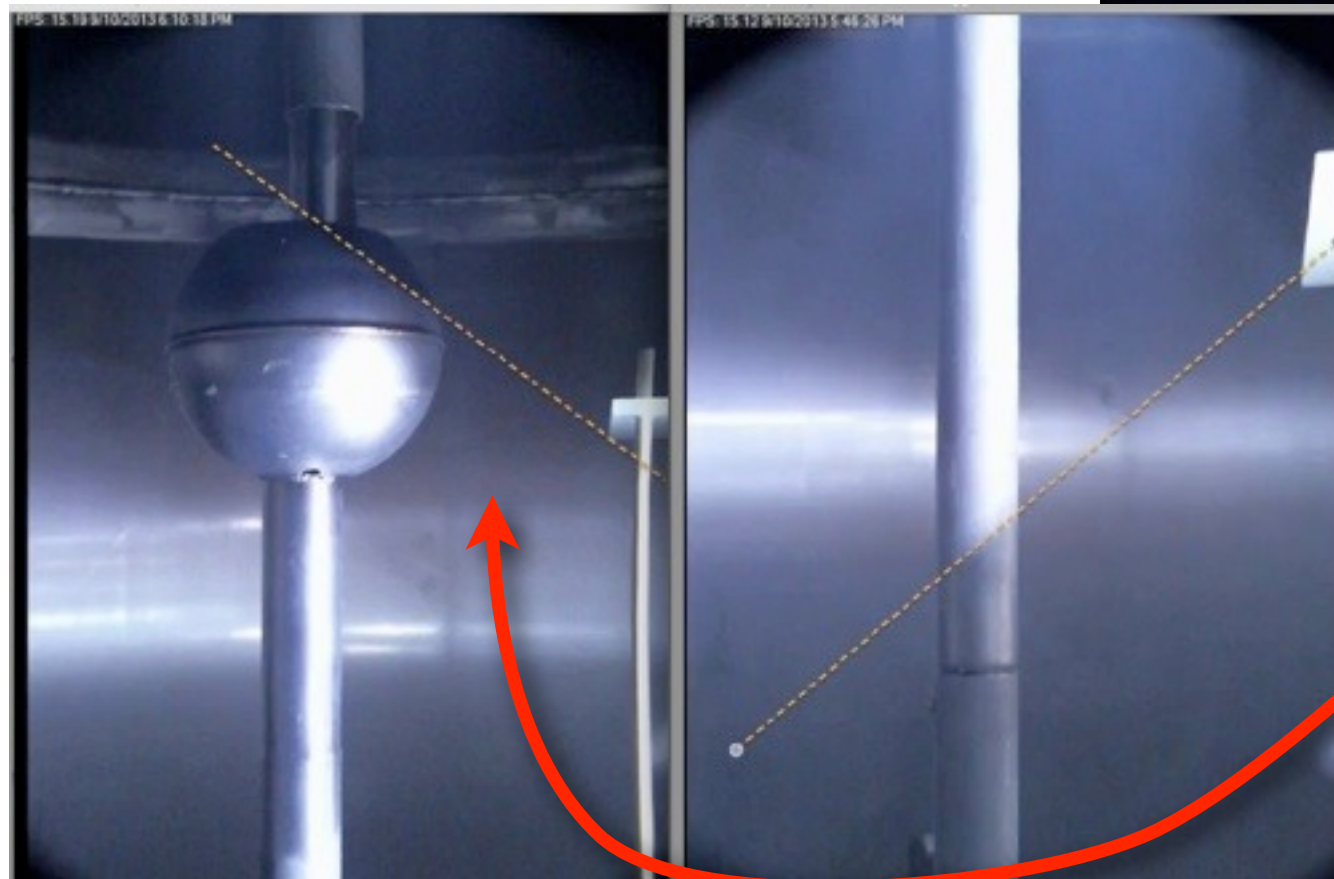
- We eventually put a camera in LAPD (provided by BERN)
- Amazing photos...



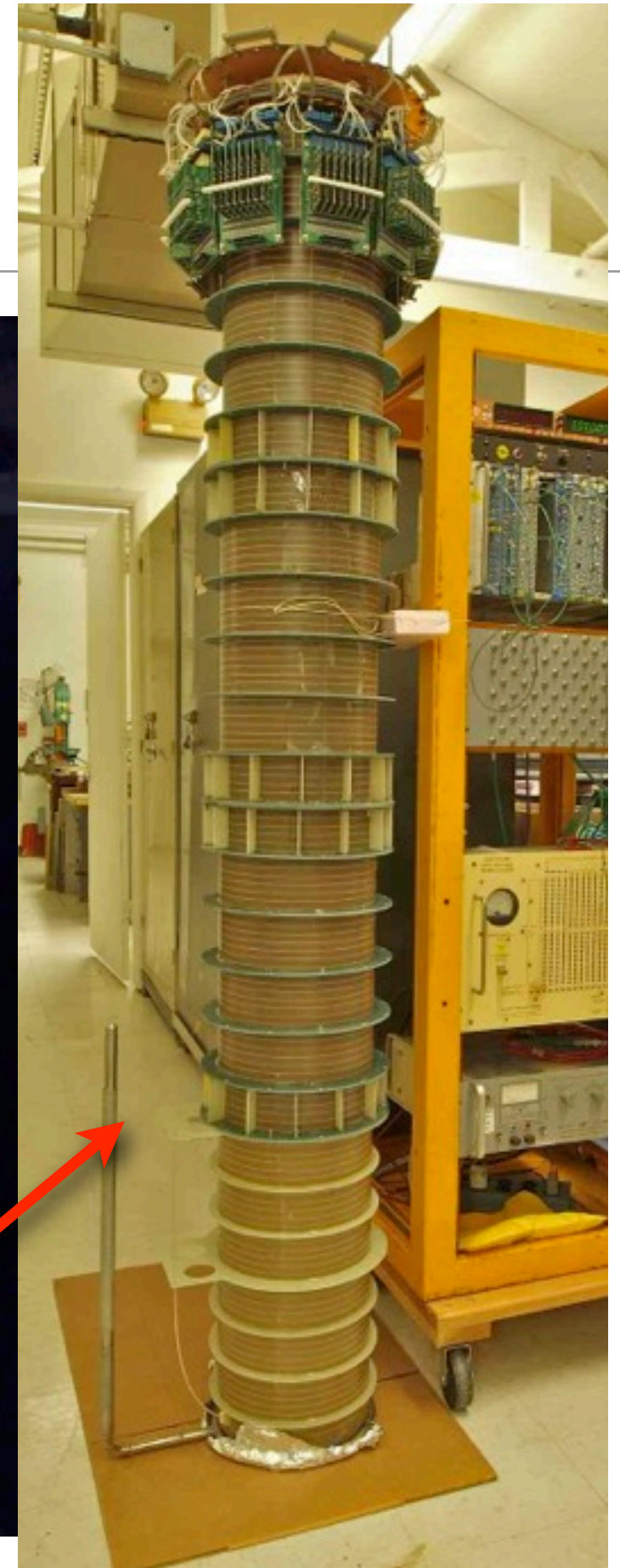


# Our Experience: Long Bo HV

- We eventually put a camera in LAPD (provided by BERN)
- Amazing photos...

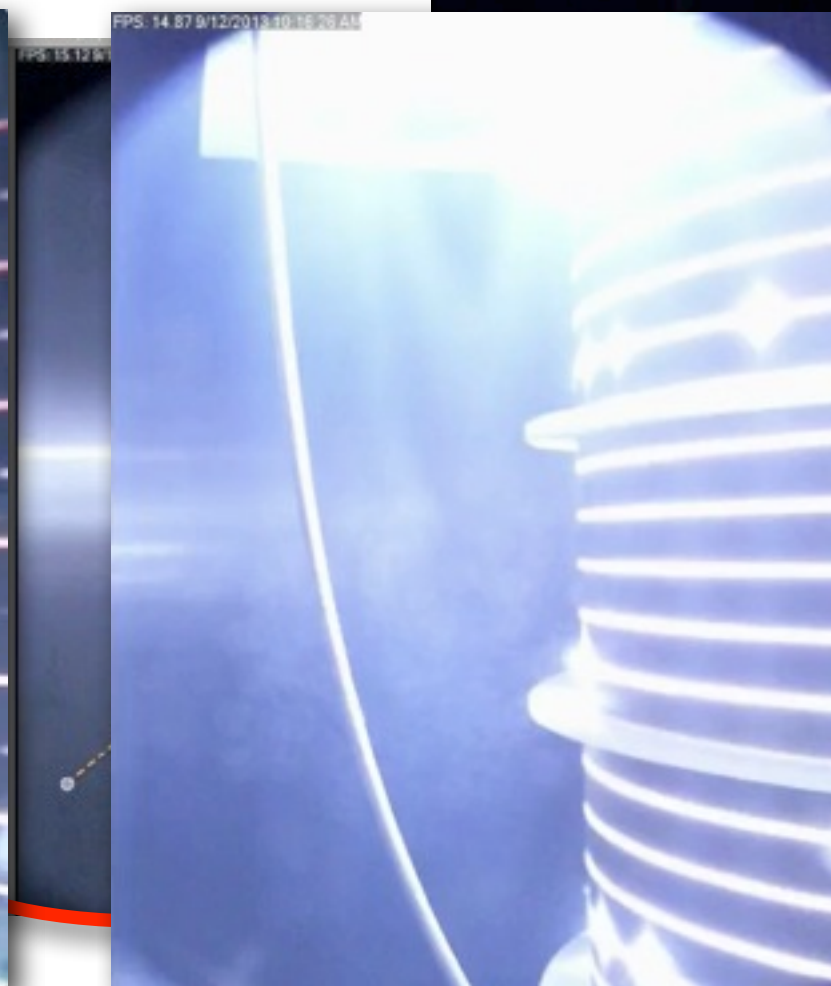
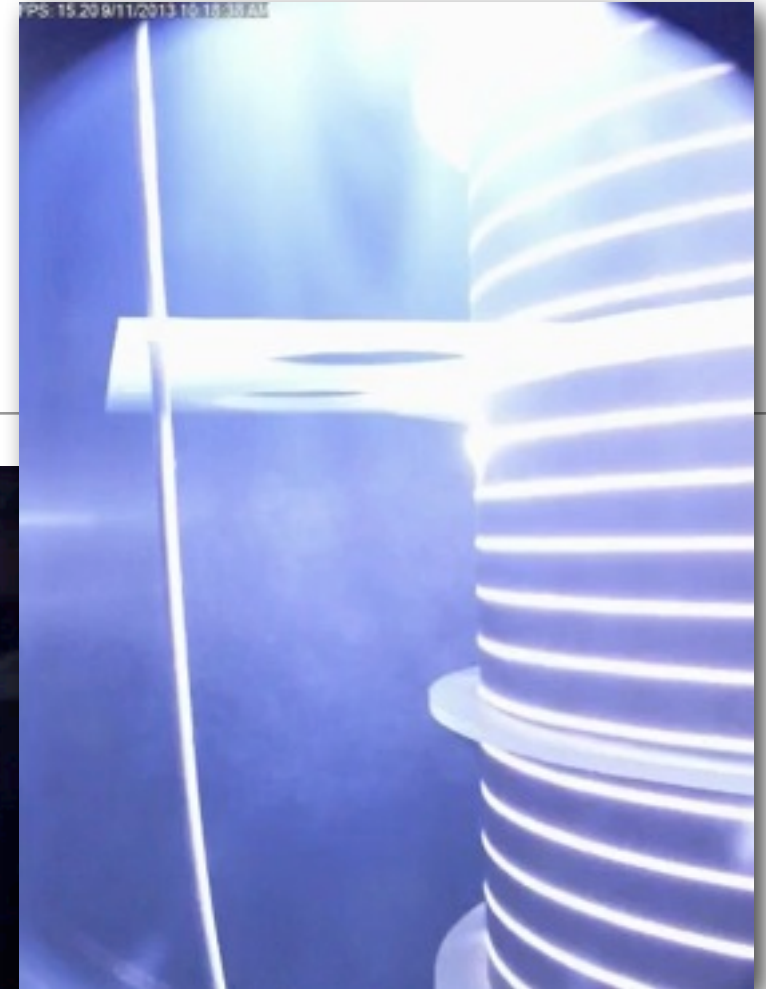
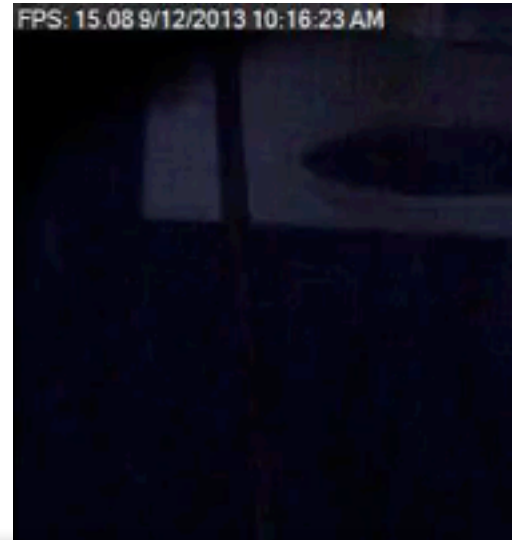


This is here



# Our Experience: Long Bo HV

- We eventually put a camera in LAPD (provided by BERN)
- Amazing photos...





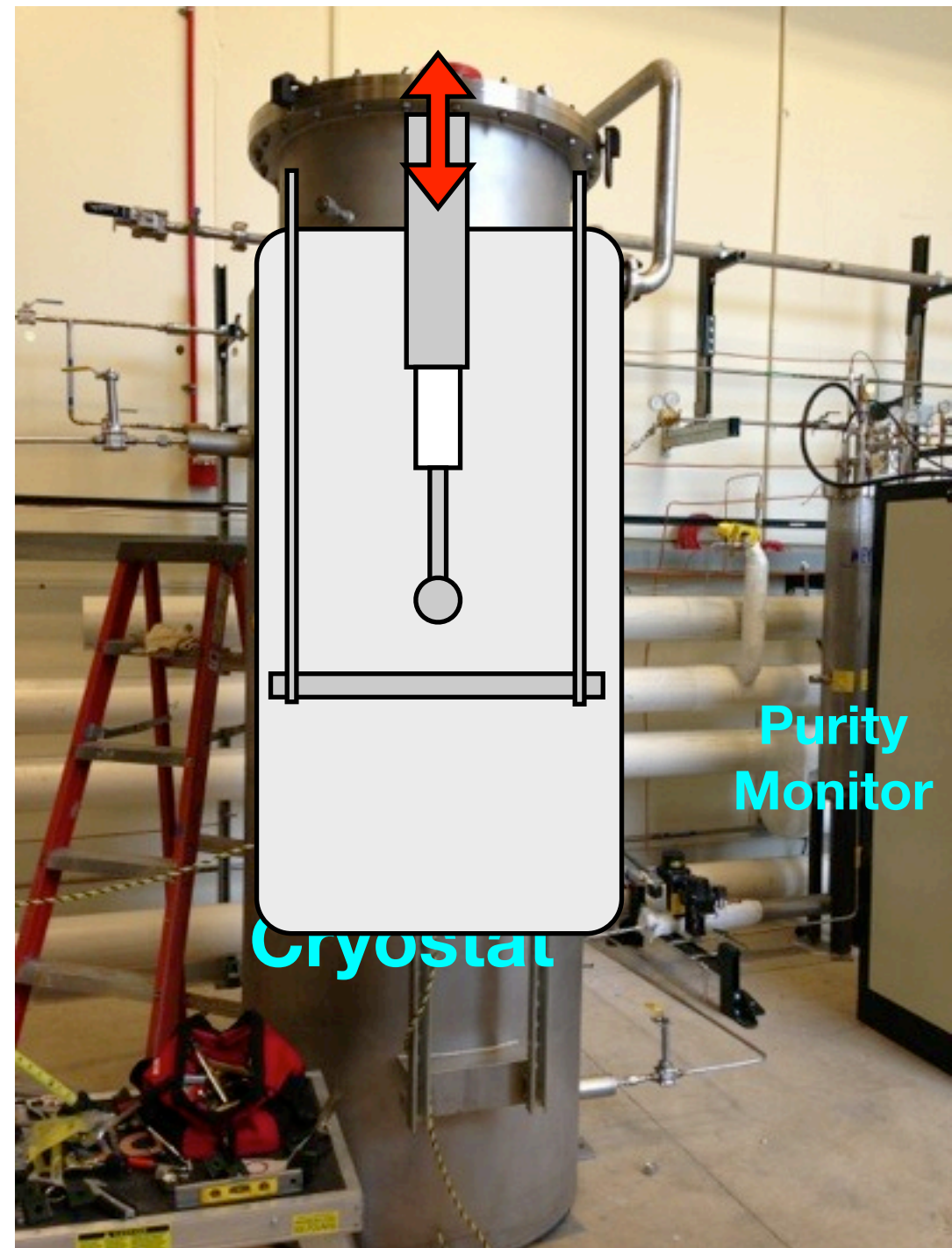
# My Experience: HVC at LArTF

- Right now, we (MicroBooNE) are redoing the LAr electric strength test vs. distance in a more controlled environment at LArTF
  - Part of the phase I cryo work
- HVC!
  - Test setup idea:



# My Experience: HVC at LArTF

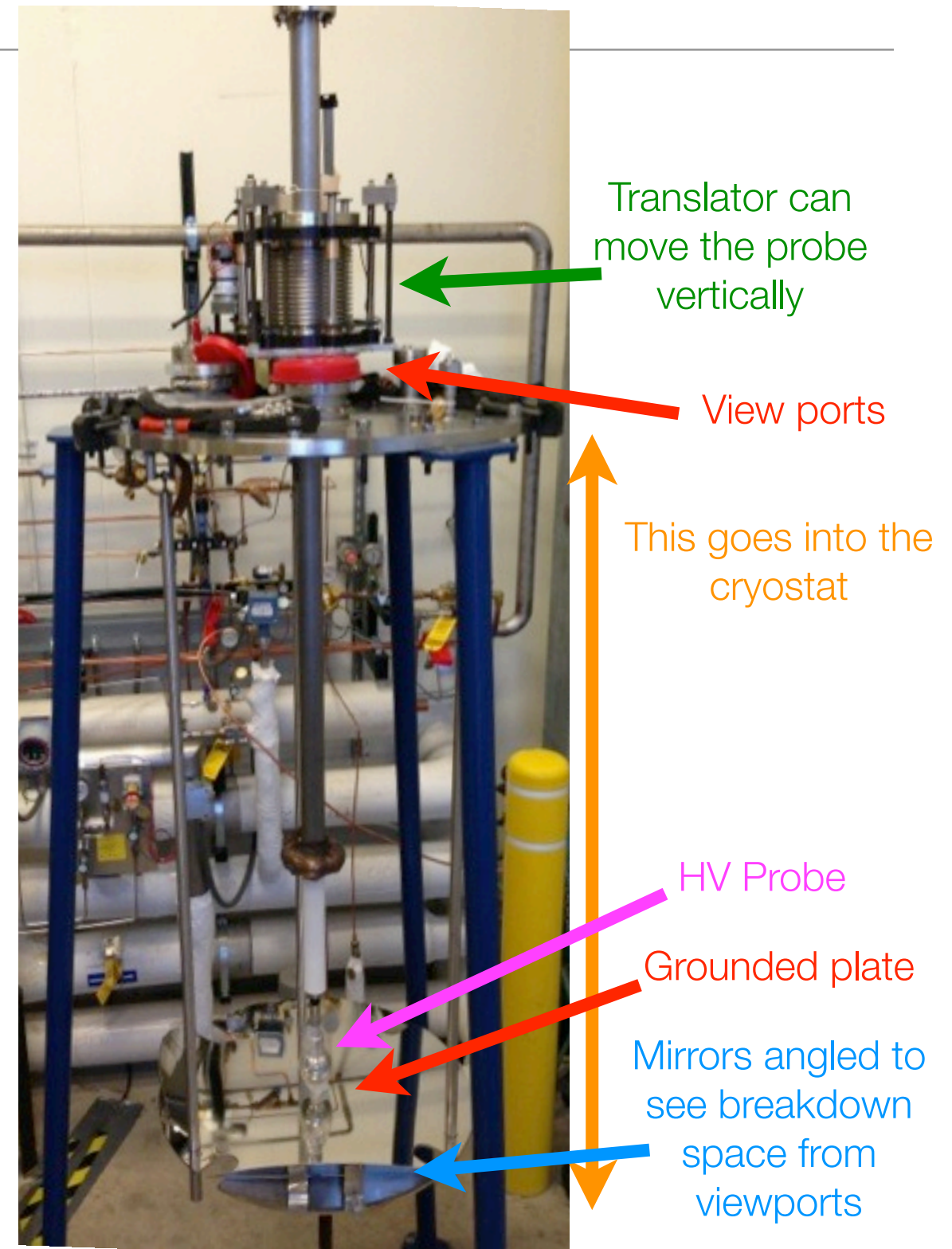
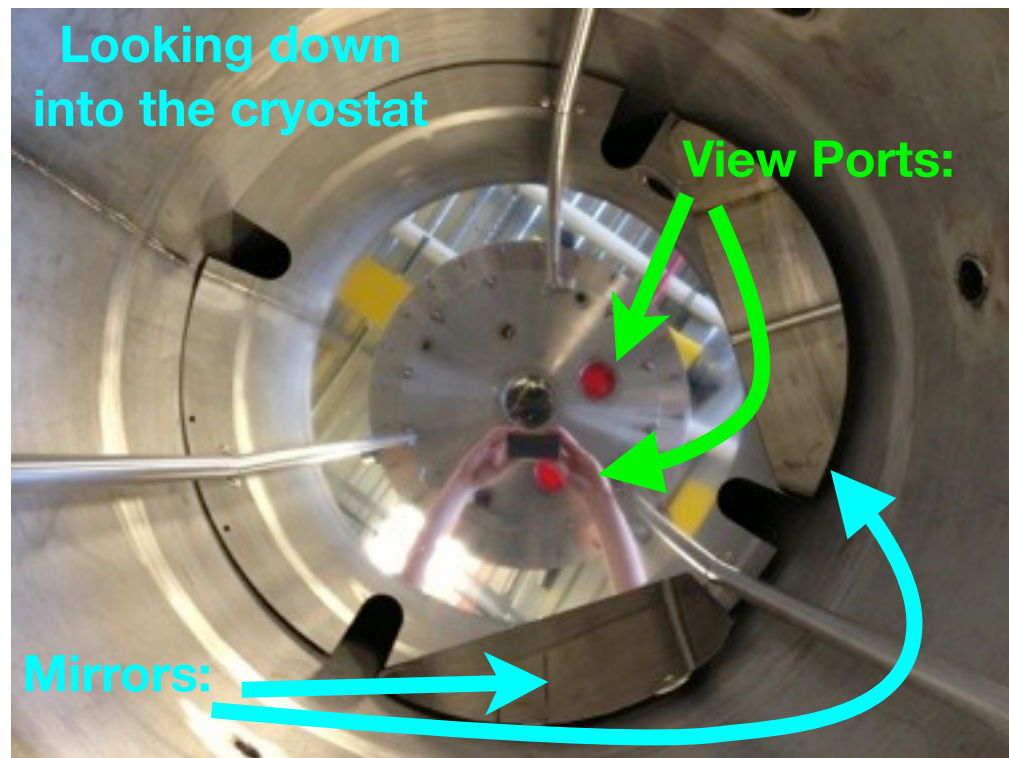
- Right now, we (MicroBooNE) are redoing the LAr electric strength test vs. distance in a more controlled environment at LArTF
  - Part of the phase I cryo work
- HVC!
  - Test setup idea:





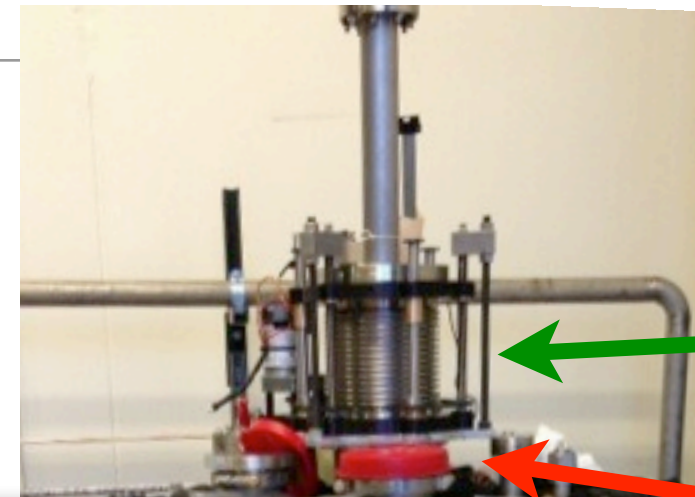
# My Experience: HVC at LArTF

- HVC Test Setup:
  - Vertical translator to control distance
  - HV FT
  - Ground Plate
  - View ports



# My Experience: HVC at LArTF

- HVC Test Setup:
  - Vertical translator to control distance
  - HV FT
  - Ground Plate
  - View ports



Translator can move the probe vertically

View ports

**Breakdown!**

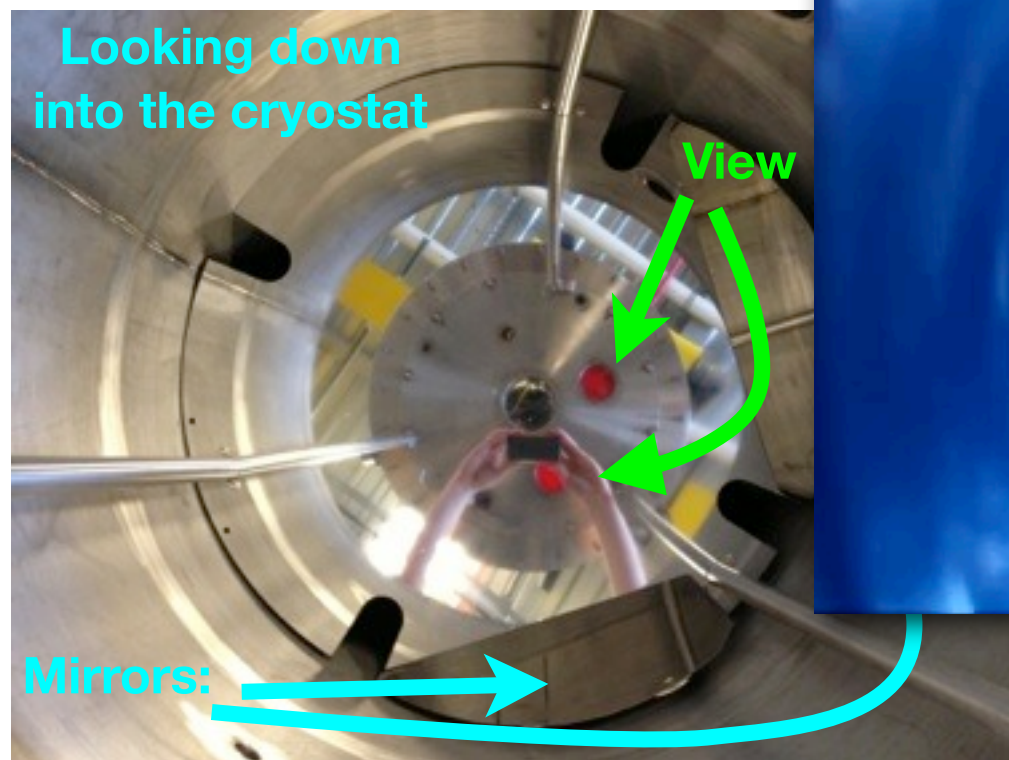
es into the  
vostat

Probe

ded plate

angled to  
see breakdown

space from  
viewports



Looking down  
into the cryostat

View

Mirrors:



# My Experience: HVC at LArTF

---

instance. The liquids must not be accepted with the arbitrary 'technical purity' from the supplier. However, the quoted strength takes no account for any size effect, i.e. the stressed liquid volume and stressed electrode area, respectively. The stressing time also can have a significant influence.

- Gerhold J., *Cryogenics*. **38** (1998) 1063-1081.

# My Experience: HVC at LArTF

---

- Sources have pointed to high field volume affecting the probability of breakdown

instance. The liquids must not be accepted with the arbitrary 'technical purity' from the supplier. However, the quoted strength takes no account for any size effect, i.e. the stressed liquid volume and stressed electrode area, respectively. The stressing time also can have a significant influence.

- Gerhold J., *Cryogenics*. **38** (1998) 1063-1081.

# My Experience: HVC at LArTF

---

- Sources have pointed to high field volume affecting the probability of breakdown
  - A trend breakdown field strength decreasing with high field volume (LHe data)

instance. The liquids must not be accepted with the arbitrary 'technical purity' from the supplier. However, the quoted strength takes no account for any size effect, i.e. the stressed liquid volume and stressed electrode area, respectively. The stressing time also can have a significant influence.

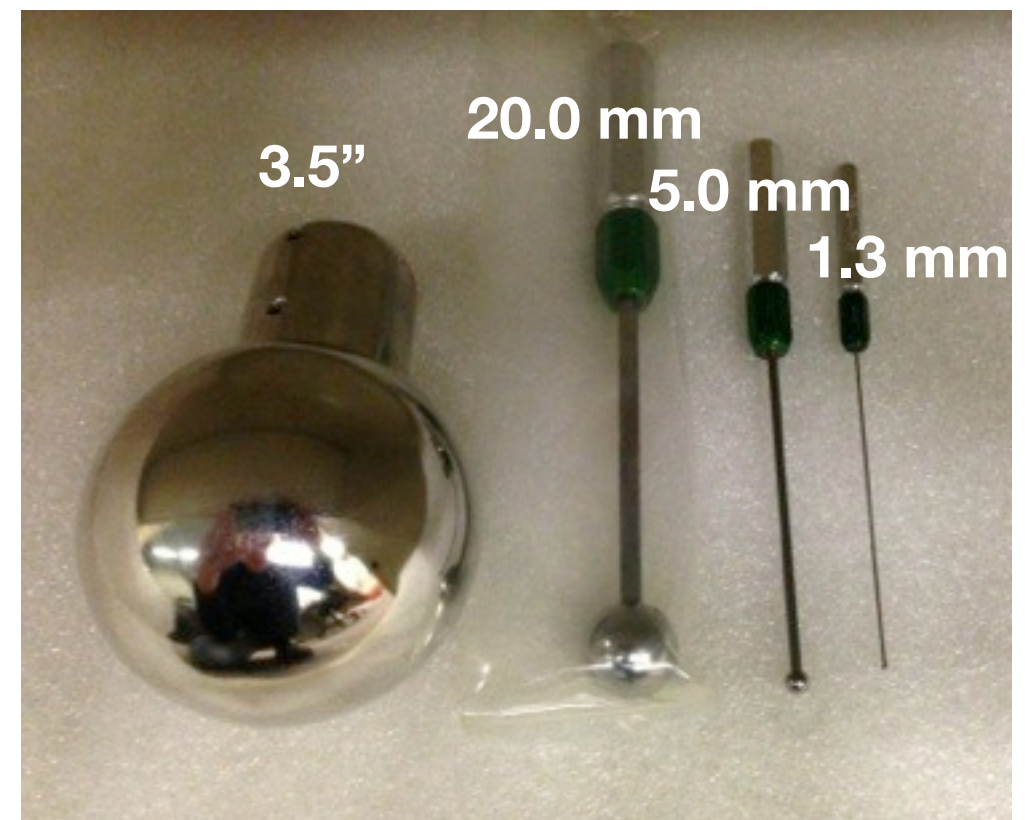
- Gerhold J., *Cryogenics*. **38** (1998) 1063-1081.

# My Experience: HVC at LArTF

- Sources have pointed to high field volume affecting the probability of breakdown
  - A trend breakdown field strength decreasing with high field volume (LHe data)
- We want to do a series of measurements with tips of different sizes to determine how the breakdown voltage varies with different E fields (high field volume)

instance. The liquids must not be accepted with the arbitrary 'technical purity' from the supplier. However, the quoted strength takes no account for any size effect, i.e. the stressed liquid volume and stressed electrode area, respectively. The stressing time also can have a significant influence.

- Gerhold J., *Cryogenics*. **38** (1998) 1063-1081.



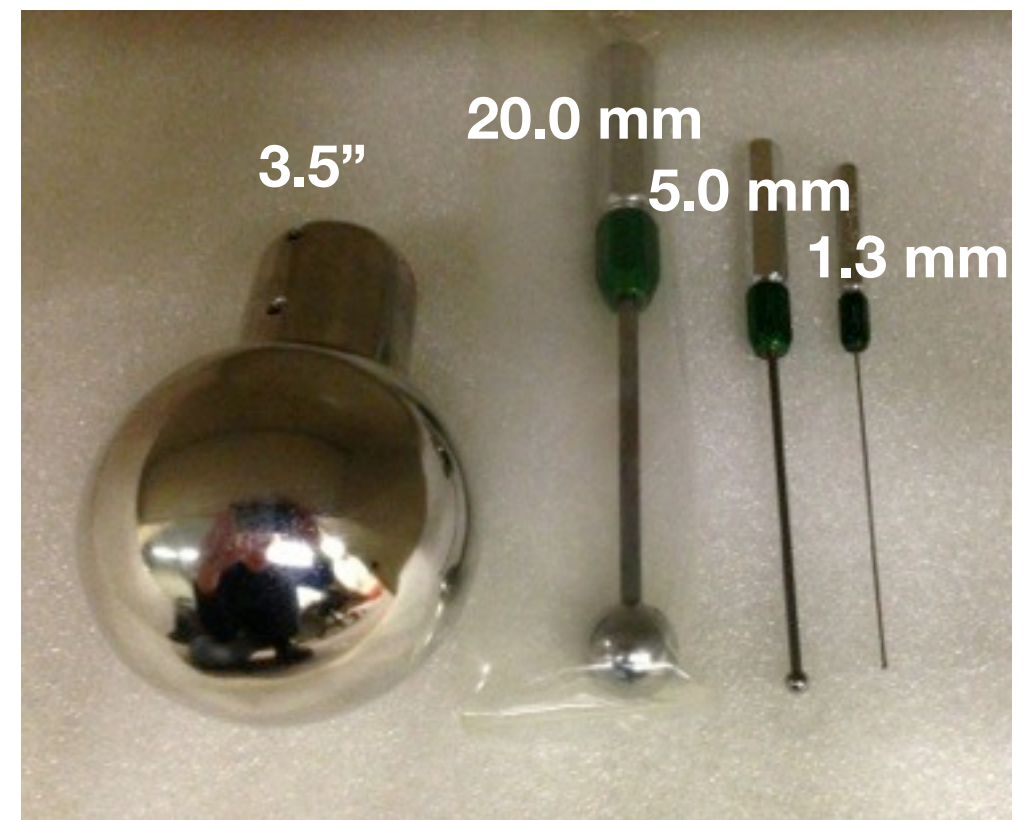


# My Experience: HVC at LArTF

- Sources have pointed to high field volume affecting the probability of breakdown
  - A trend breakdown field strength decreasing with high field volume (LHe data)
- We want to do a series of measurements with tips of different sizes to determine how the breakdown voltage varies with different E fields (high field volume)
- We want to measure how the breakdown voltage is affected by purity
  - Gas analyzers

instance. The liquids must not be accepted with the arbitrary 'technical purity' from the supplier. However, the quoted strength takes no account for any size effect, i.e. the stressed liquid volume and stressed electrode area, respectively. The stressing time also can have a significant influence.

- Gerhold J., *Cryogenics*. **38** (1998) 1063-1081.

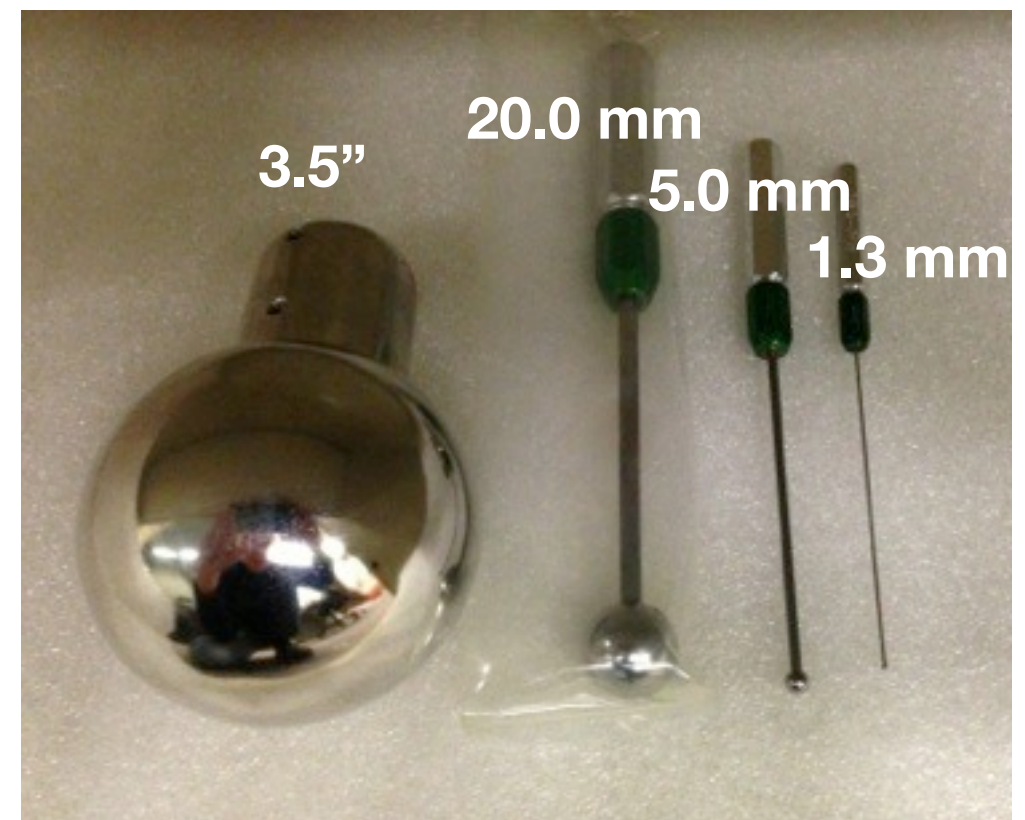


# My Experience: HVC at LArTF

- Sources have pointed to high field volume affecting the probability of breakdown
  - A trend breakdown field strength decreasing with high field volume (LHe data)
- We want to do a series of measurements with tips of different sizes to determine how the breakdown voltage varies with different E fields (high field volume)
- We want to measure how the breakdown voltage is affected by purity
  - Gas analyzers
  - Purity monitor downstream

instance. The liquids must not be accepted with the arbitrary 'technical purity' from the supplier. However, the quoted strength takes no account for any size effect, i.e. the stressed liquid volume and stressed electrode area, respectively. The stressing time also can have a significant influence.

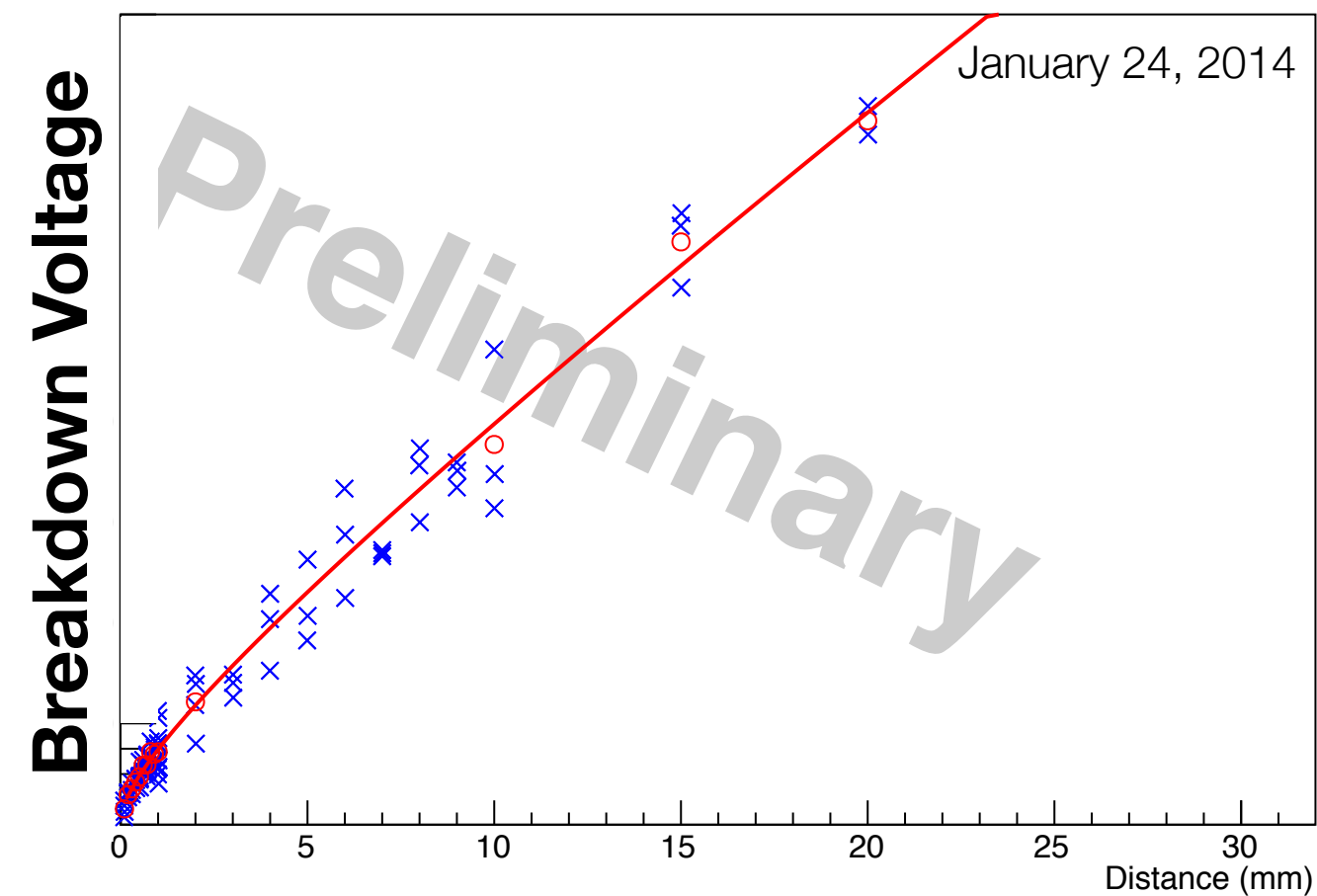
- Gerhold J., *Cryogenics*. **38** (1998) 1063-1081.



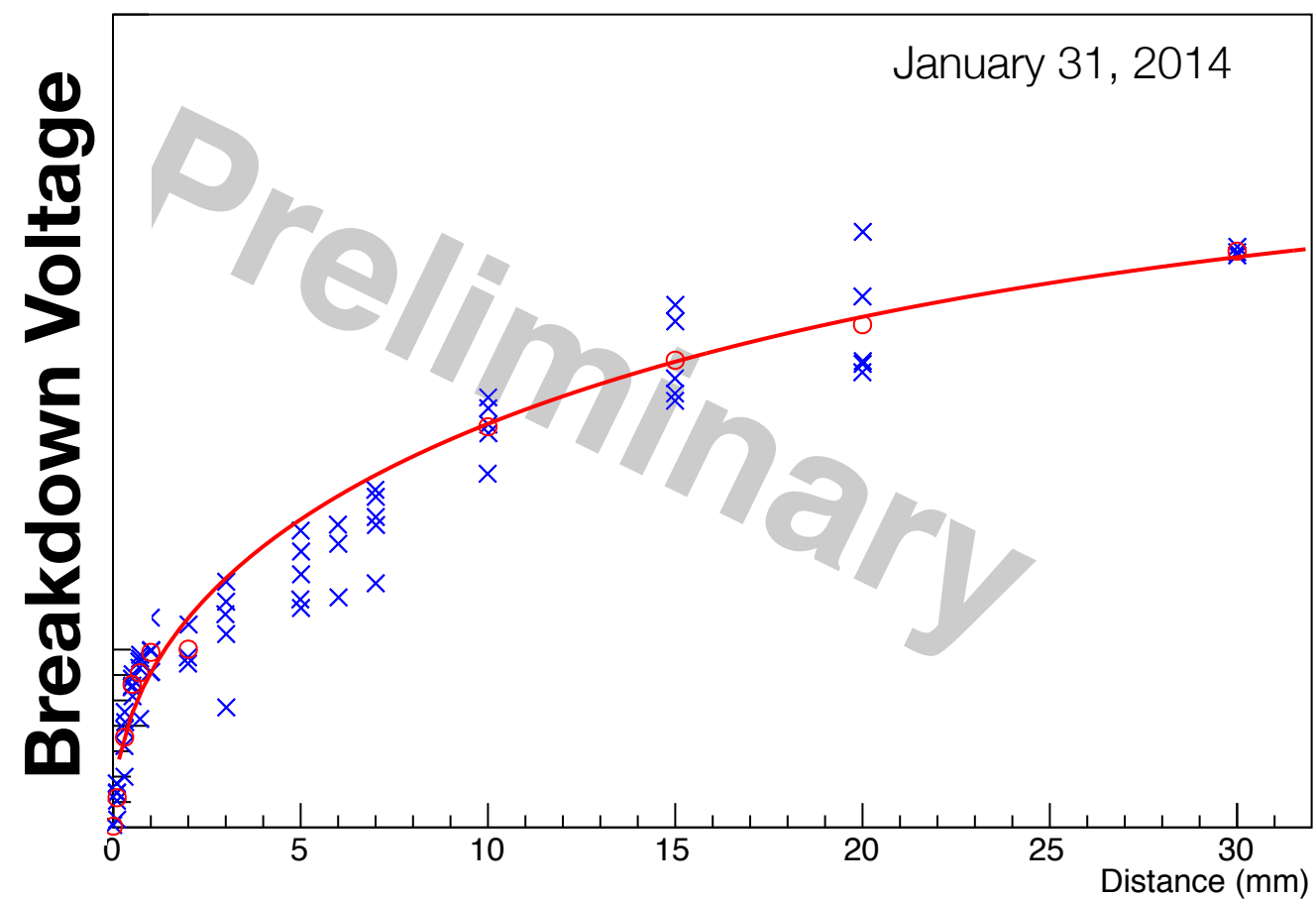


# My Experience: HVC at LArTF

3.5" Sphere Breakdown Voltage vs. Distance



5 mm Sphere Breakdown Voltage vs. Distance



# What We Would Like To Do: Finish First Phase

---

# What We Would Like To Do: Finish First Phase

---

- I would like to:

# What We Would Like To Do: Finish First Phase

---

- I would like to:
  - Measure effect vs. **purity**, **distance**, and **high field volume** (vary the probe shape)
- These results will be noteworthy in that
  - The feedthrough works to the power supply limit (150 kV) (BERN 55 kV)

# What We Would Like To Do: Finish First Phase

---

- I would like to:
  - Measure effect vs. **purity**, **distance**, and **high field volume** (vary the probe shape)
- These results will be noteworthy in that
  - The feedthrough works to the power supply limit (150 kV) (BERN 55 kV)
  - We can vary distance (Resnati was fixed at 1cm)
  - We can study the effects of high field volume (probe size)

**Others do not seem  
to be studying this**

Additionally, We Would like to...

---



**Others do not seem  
to be studying this**

## Additionally, We Would like to...

---

- Study the effects of additives on HV stability
  - Stability vs. purity effects suggest that impurities might lead to HV stability
  - PAB has a system to inject known amounts of impurities into a system

**Others do not seem  
to be studying this**

## Additionally, We Would like to...

---

- Study the effects of additives on HV stability
  - Stability vs. purity effects suggest that impurities might lead to HV stability
  - PAB has a system to inject known amounts of impurities into a system
- Study the effect of surface material and conditions on electric discharge
  - Is electropolishing necessary? Other surface treatments...
- Test polarity effects

**Others do not seem  
to be studying this**

## Additionally, We Would like to...

---

- Study the effects of additives on HV stability
  - Stability vs. purity effects suggest that impurities might lead to HV stability
  - PAB has a system to inject known amounts of impurities into a system
- Study the effect of surface material and conditions on electric discharge
  - Is electropolishing necessary? Other surface treatments...
- Test polarity effects
  - It's natural to ask how the results change if a +V is applied (instead of -V)
  - (Positive supply is available onsite -- some logistic contortions are needed to free it)

# Light & Radioactivity

---

**Others do not seem  
to be studying this**

**Others do not seem  
to be studying this**

# Light & Radioactivity

---

- How light affects HV
  - We know UV light can trigger a breakdown (unpublished test with H.Jostlein)
  - It's sometimes mentioned that light could be a precursor for HV sparks

# Light & Radioactivity

---

- How light affects HV
  - We know UV light can trigger a breakdown (unpublished test with H.Jostlein)
  - It's sometimes mentioned that light could be a precursor for HV sparks
- The effect of radioactivity on HV
  - Heavy particles such as neutrons or alpha particles are sometimes mentioned as the culprit for delayed breakdowns



# In Closing... (1/3)

---

# In Closing... (1/3)

---

- I do not think the mechanisms or parameters for breakdown in LAr are well understood

# In Closing... (1/3)

---

- I do not think the mechanisms or parameters for breakdown in LAr are well understood
- First, we intend to complete the study of breakdown voltage vs. distance
  - vs. purity
  - vs. configuration -- high field volume
  - (eventually) surface

# In Closing... (1/3)

---

- I do not think the mechanisms or parameters for breakdown in LAr are well understood
- First, we intend to complete the study of breakdown voltage vs. distance
  - vs. purity
  - vs. configuration -- high field volume
  - (eventually) surface
- These measurements have notable strengths over others' endeavors
  - FT performance
  - Range of movement
  - Range of purities
  - Probe shape

# In Closing (2/3)

---

# In Closing (2/3)

---

- What we will need:
  - To establish the system at the PAB: Bringing the cryostat from LArTF
    - Approximately \$50,000 M&S: cryogenic hardware, machining, welding
      - Feedthroughs, condenser, internal filter, hook up to existing argon source, consultant, purity monitoring system, DAQ, hook up to gas analyzers, controls, camera
  - 3 months tech (\$40k); 1 month engineer (\$25k)



# In Closing (3/3)

---

# In Closing (3/3)

---

1. *Briefly summarize the current state of the program, discussing what has been learned and what are the remaining issues.*

1.1. People have made HV feedthroughs, but it seems to be more of an art than a science. It remains to make some basic measurements to try and elucidate the causes of breakdowns.

# In Closing (3/3)

---

1. *Briefly summarize the current state of the program, discussing what has been learned and what are the remaining issues.*

1.1. People have made HV feedthroughs, but it seems to be more of an art than a science. It remains to make some basic measurements to try and elucidate the causes of breakdowns.

2. *What is the proposed scope of the R&D program for the next two years, and what resources are required for that program*

2.1. I am asking for funds and support to continue this work by bringing the MicroBooNE HVC to PAB to integrate into the existing systems, and to develop a capability for studies.

# In Closing (3/3)

---

1. *Briefly summarize the current state of the program, discussing what has been learned and what are the remaining issues.*
  - 1.1. People have made HV feedthroughs, but it seems to be more of an art than a science. It remains to make some basic measurements to try and elucidate the causes of breakdowns.
2. *What is the proposed scope of the R&D program for the next two years, and what resources are required for that program*
  - 2.1. I am asking for funds and support to continue this work by bringing the MicroBooNE HVC to PAB to integrate into the existing systems, and to develop a capability for studies.
3. *Compare the program with similar programs worldwide. Are we doing leading work in this area?*
  - 3.1. HV is an area of common interest, but I think I've identified capabilities and interests that are unique here.

# In Closing (3/3)

---

1. *Briefly summarize the current state of the program, discussing what has been learned and what are the remaining issues.*
  - 1.1. People have made HV feedthroughs, but it seems to be more of an art than a science. It remains to make some basic measurements to try and elucidate the causes of breakdowns.
2. *What is the proposed scope of the R&D program for the next two years, and what resources are required for that program*
  - 2.1. I am asking for funds and support to continue this work by bringing the MicroBooNE HVC to PAB to integrate into the existing systems, and to develop a capability for studies.
3. *Compare the program with similar programs worldwide. Are we doing leading work in this area?*
  - 3.1. HV is an area of common interest, but I think I've identified capabilities and interests that are unique here.
4. *Which parts of the program should be considered generic R&D and which parts should be considered project specific?*
  - 4.1. I expect our measurements will be of general interest, but this is not focused on any specific project.

# In Closing (3/3)

---

1. *Briefly summarize the current state of the program, discussing what has been learned and what are the remaining issues.*

1.1. People have made HV feedthroughs, but it seems to be more of an art than a science. It remains to make some basic measurements to try and elucidate the causes of breakdowns.

2. *What is the proposed scope of the R&D program for the next two years, and what resources are required for that program*

2.1. I am asking for funds and support to continue this work by bringing the MicroBooNE HVC to PAB to integrate into the existing systems, and to develop a capability for studies.

3. *Compare the program with similar programs worldwide. Are we doing leading work in this area?*

3.1. HV is an area of common interest, but I think I've identified capabilities and interests that are unique here.

4. *Which parts of the program should be considered generic R&D and which parts should be considered project specific?*

4.1. I expect our measurements will be of general interest, but this is not focused on any specific project.

5. *Will this research likely result in new projects at the lab?*

5.1. Absolutely not.



# In Closing (3/3)

---

1. *Briefly summarize the current state of the program, discussing what has been learned and what are the remaining issues.*

1.1. People have made HV feedthroughs, but it seems to be more of an art than a science. It remains to make some basic measurements to try and elucidate the causes of breakdowns.

2. *What is the proposed scope of the R&D program for the next two years, and what resources are required for that program*

2.1. I am asking for funds and support to continue this work by bringing the MicroBooNE HVC to PAB to integrate into the existing system.

3. *Compare the program with similar programs*

3.1. HV is an area of common interest unique here.

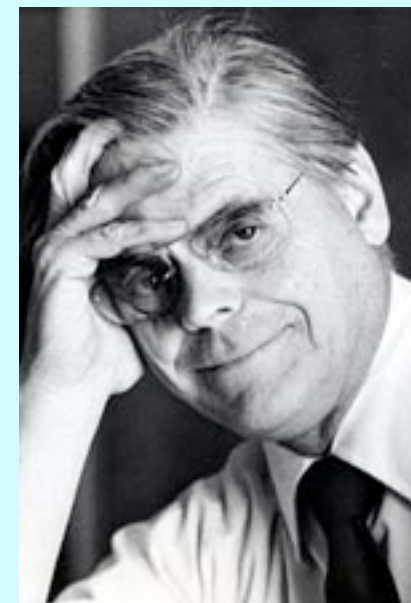
4. *Which parts of the program should be considered project specific?*

4.1. I expect our measurements will project.

5. *Will this research likely result in new projects?*

5.1. Absolutely not.

*"It has only to do with the respect with which we regard one another, the dignity of men, our love of culture. It has to do with those things."  
--R. Wilson, 1969.*



Back Up Slides

**Others seem to  
be studying this**

# Study Bubbles and Temperature

---

# Study Bubbles and Temperature

- Study the effect of bubbles
  - This is often mentioned as a breakdown mechanism/mode (electric strength of Ar gas is only  $\sim 1.6$  kV/cm)
  - Is the narrative actually true? Bubbles do not always initiate a breakdown

## R&D on HV

- Unknowns to be known before the final design:
  - Liquid argon dielectric rigidity versus electrode distance
  - Bubble and liquid argon purity effects on discharges
  - Argon ionization and space charge effects
  - Electrode material impact and properties of insulating materials

Filippo Resnati - High Voltage in Noble Liquids - FNAL - November 9th, 2013

24

**Others seem to  
be studying this**

# Study Bubbles and Temperature

- Study the effect of bubbles
  - This is often mentioned as a breakdown mechanism/mode (electric strength of Ar gas is only  $\sim 1.6$  kV/cm)
  - Is the narrative actually true? Bubbles do not always initiate a breakdown
- Study the temperature dependence
  - Source of bubble = bad ?
  - There is an idea that argon plates out on cold surfaces trapping impurities that lead to HV sparks:

## R&D on HV

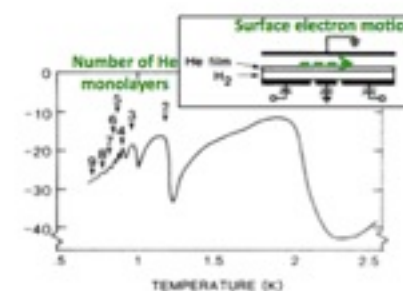
- Unknowns to be known before the final design:
  - Liquid argon dielectric rigidity versus electrode distance
  - Bubble and liquid argon purity effects on discharges
  - Argon ionization and space charge effects
  - Electrode material impact and properties of insulating materials

Filippo Resnati - High Voltage in Noble Liquids - FNAL - November 9th, 2013

24

## Solid Physisorbed Films of Noble Gases

### Solid He films on H<sub>2</sub> surfaces



- Solid He monolayers form on solid H<sub>2</sub> surfaces
- They will also form on metal surfaces at low T
- Ar, Kr and Xe do the same  
L.W. Brush et al., Rev. Mod. Phys. 79 (2007)
- Ar, Kr, and Xe monolayers reduce work function  
F. Forster et al., J. Phys. Chem. B 108, 14692 (2004)  
C. Huuckstadt et al., Phys. Rev. B 73, 075409 (2006)

- Measure electron surface mobility
- Peaks at filled He monolayer(s)  
Cieslikowski et al., PRL 58 (1987)

Noble gases will *always* form a dielectric on metal surfaces at low temperatures.

# Study Delayed Breakdowns

---

**Others do not seem  
to be studying this**



**Others do not seem  
to be studying this**

# Study Delayed Breakdowns

---

- Study delayed breakdowns

**Others do not seem  
to be studying this**

# Study Delayed Breakdowns

---

- Study delayed breakdowns
  - While testing the HV FT, we noted sometimes the FT would be stable for a number of days before observing a trip

**Others do not seem  
to be studying this**

# Study Delayed Breakdowns

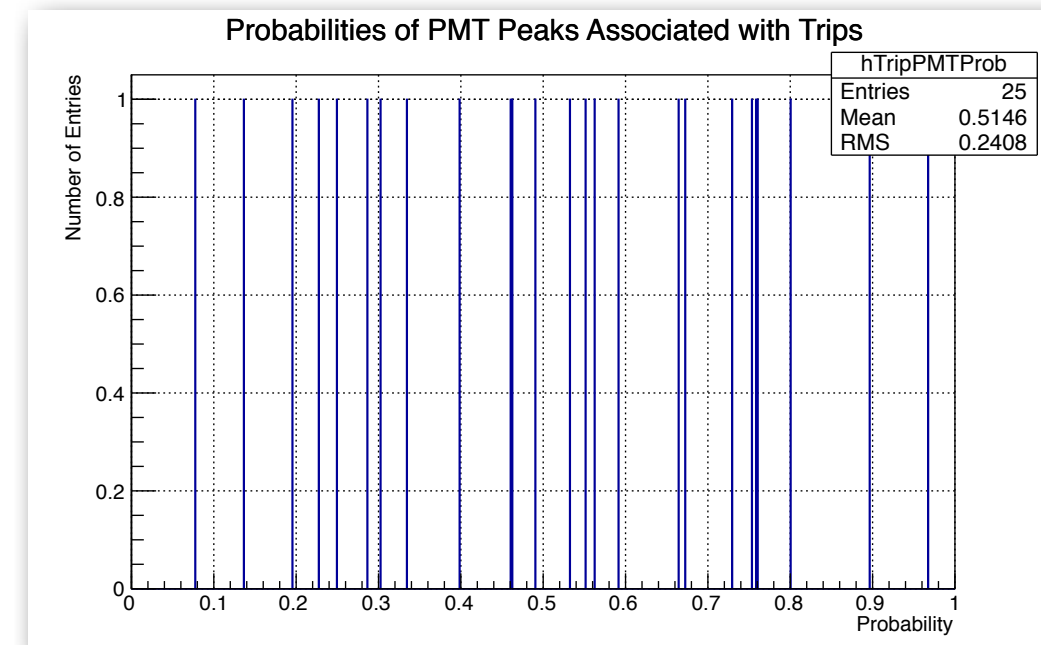
---

- Study delayed breakdowns
  - While testing the HV FT, we noted sometimes the FT would be stable for a number of days before observing a trip
  - An idea was that cosmic showers were triggering the breakdowns

**Others do not seem  
to be studying this**

# Study Delayed Breakdowns

- Study delayed breakdowns
  - While testing the HV FT, we noted sometimes the FT would be stable for a number of days before observing a trip
  - An idea was that cosmic showers were triggering the breakdowns
  - We did an initial test of this at LAPD
    - The counter had limited coverage (~35x35 scintillator ~12' above the TPC)
    - No correlation (lartpc docdb #1001)
  - We could redo this test and easily improve the coverage



**Others might be  
studying this**

# Would like to study

---

# Would like to study

---

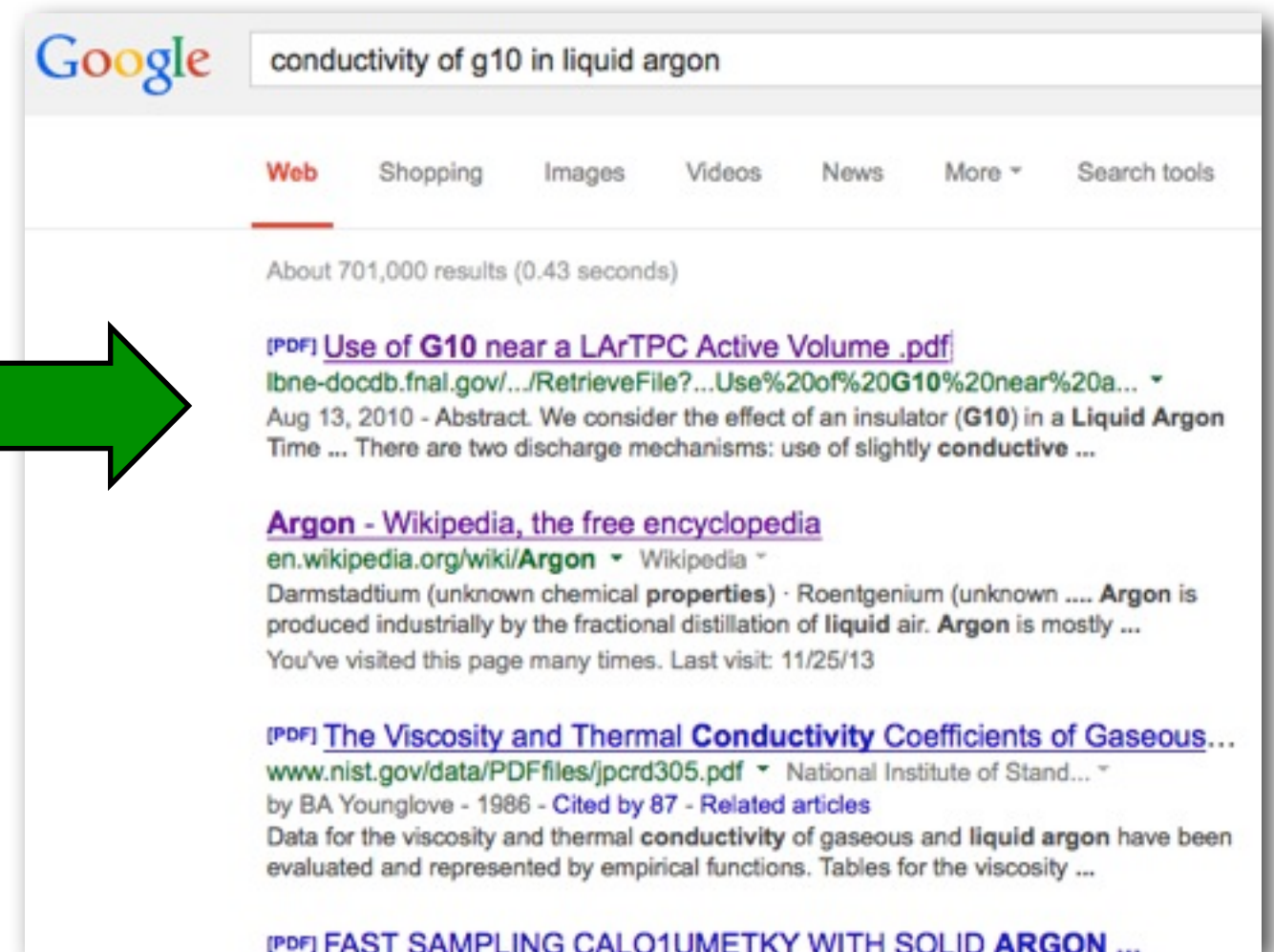
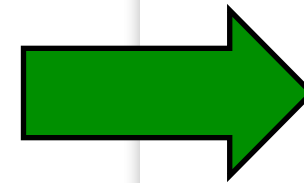
- Surface conductivities in LAr



**Others might be studying this**

# Would like to study

- Surface conductivities in LAr
  - These values do not seem to be listed anywhere
    - A google check of “conductivity of g10 in liquid argon” brings up a Hans document as the first hit



**Others might be studying this**

# Would like to study

- Surface conductivities in LAr
  - These values do not seem to be listed anywhere
    - A google check of “conductivity of g10 in liquid argon” brings up a Hans document as the first hit
- I don't know how to do this

